Vol. 5 December 1959 No. 2

BIOLOGIA

CONTENTS

LATIF, A., HAQUE, K.A. & KHAN, M.R.—The external anatomy of *Poecilocerus pictus* (Fb.).....143

KHAN, A.H.—Biology and pathogenicity of *Rosellinia necatrix*.....199

Published by

THE BIOLOGICAL SOCIETY OF PAKISTAN

Biological Laboratories, Government College,
LAHORE

NLP KRAM

COMMONWEALTH MYCOLOGICAL 9 SEP 1960

Biologia is published twice a year by The Biological Society of Pakistan, Lahore. The journal is available in exchange for publications of a similar character.

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The external anatomy of Poecilocerus pictus (Fb.)

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CONTENTS

Introduction 144
Material and methods 144
The head 145
(i) The head capsule or cranium 145
(ii) The head appendages 150
The thorax 154
(i) The prothorax 155
(ii) The pterothorax 157
A. The pterothoracic terga 157
B. The pterothoracic pleura 159
C. The pterothoracic sterna 160
(iii) The wings 161
A. The venation 162
B. The wing articulation 163
(iv) The legs 165
The abdomen 167
(i) The general structure 167
(ii) The ovipositor 169
(iii) The male genitalia 170
Summary 172
References 173
List of figures 175
List of abbreviations 176

INTRODUCTION

Poecilocerus pictus (Fb.), known commonly as 'ak-grasshopper' because it feeds on 'ak' (*Calotropis*), is available in plenty during summer and early autumn in the greater part of the Indo-Pakistan sub-continent. It is big in size and convenient to handle and represents the generalized morphological features of an insect sufficiently well. Hence, it is used as a type for teaching insect morphology and anatomy in many educational ins'itutions in this sub-continent. But it is unfortunate that no authenticated and up-to-date published account of its anatomy is available.

In teaching the morphology and anatomy of this insect, therefore, the teacher has to depend for guidance largely on the descriptions given by MacGillivray (1923) and Snodgrass (1928, 1929 and 1935) about other grasshoppers. Some of the terminology used in these old works has become out of date in the light of recent advances made in the morphology of grasshoppers according to the works of Albrecht (1953 and 1956), Misra (1945, 1946 and 1947) and Dirsh (1956). The most useful recent contribution is that by Albrecht (1953), who has published a monograph on the anatomy of migratory locust. Since the availability of migratory locust cannot be ensured every year for teaching in this sub-continent, this work has a limited utility here. Hence, it became essential to carry out a detailed study of the anatomy of our own common grasshopper, *Poecilocerus pictus*, to serve the needs of the teacher and the taught in the field of entomology in our country.

MATERIAL AND METHODS

The material used in this study was collected from about the middle of March to about the end of September mostly from 'ak' (*Calotropis*), a wild plant growing in plenty around Lyallpur. The specimens were preserved in formalin.

For the study of external anatomy the various parts were dissected out and then boiled in KOH (10%) for about 5 minutes. The material thus cleared was treated with glacial acetic acid (10%) for about 5 minutes to remove traces of KOH and then washed with distilled water and dehydrated in the ascending grades of alcohol from 30 percent to 70 percent. The specimens were then stained with carbol fuchsin and washed in 70 percent alcohol and dehydrated in absolute alcohol. The material thus

treated was cleared in clove oil for about two hours and before mounting in canada balsam was given a dip in xylol for about one minute. Drawings were made with the help of Abbe camera lucida.

THE HEAD

The head of *P. pictus* is hypognathous. It preserves the generalized acridine orientation in having the face directed forward and the mouth appendages hanging downwards. Strong sclerotization is noticed on its anterior, dorsal and lateral walls. As is the case in many other grasshoppers, the fastigium of the vertex is produced considerably forward giving it a characteristic shape. Posteriorly, the head is attached to the prothorax by means of neck membrane termed as cervicum.

The head has been considered under two headings, (i) the head capsule or cranium, and (ii) the head appendages.

(i) The Head Capsule or Cranium

(Figs. 1-5)

The anterior, lateral and dorsal sclerotized walls of the head form a capsule in which the sclerites have undergone extensive fusion. Ventrally, the head is limited by the bases of the mandibles, the maxillae and a medially placed hypopharynx. The occipital foramen (Fig. 4, For., foramen of Albrecht, 1953) is closed ventrally by the neck membrane, in which the base of the labium (submentum) is suspended. A well formed tentorium furnishes internal skeleton to the head capsule.

a. THE HEAD SCLERITES (Figs. 1,2,4 & 5). The head capsule is constituted by the following distinct sclerites: the *frons* (Figs. 1,2 & 3, Fr), the *clypeus* (Figs. 2 & 3, Clp) and the *labrum* (Figs. 1,2 & 3, Lm), the *parietals* (Figs. 2 & 5, VX, ge), the *subgenal area* (Fig. 2, Sg), the *occipital arch* (Figs. 2 & 4, Oc, Pge) and the *postocciput* (Fig. 4, Poc). Snodgrass (1935) refers to parietals as the areas formed by the *vertex* (Fig. 2 & 5, VX) and *genae* (Fig. 4, ge) put together on each side.

The *epicranial suture* is only superficially marked on the head, its main stem or *coronal suture* (Figs. 4 & 5, Cs) extends forward from near the occiptal foramen (Fig. 4, For) in the form of mid-dorsal line which terminates near the anterior margin of the vertex. Two small frontal sutures (Fig. 5, Fs), originating from near the anterior borders of the compound eyes, meet it obliquely a little before its anterior

termination, giving it a characteristic arrow-shaped appearance. Thus, in *P. pictus* the arms of the so-called "Y" shaped epicranial suture are reversed in position as compared with the situation in other grasshoppers, e.g., *Dissosteira carolina* (Snodgrass, 1928) and *Locusta migratoria* (Albrecht, 1953).

b. THE FRONS (Figs. 1 & 2, Fr). *Frons* is a well formed and large sized sclerite. However, the exact delineation and definition of the limiting sutures is somewhat difficult mainly on account of the disposition of the *frontal suture* (Fig. 5, Fs) and the *subocular suture* (Fig. 1, S.o.s).

The following is the description of the limiting sutures of frons. Ventrally, frons is limited by *epistomal* (fronto-clypeal) *suture* (Fig. 1, E. S). On the laterals, it is bounded by the *frontogenal sutures* (Fig. 1, FGS). Each frontogenal suture extends from the base of the antenna of its side to the epistomal suture, meeting the latter laterad to anterior tentorial pits (Fig. 1, at). Dorsally, the disposition of the arrow-shaped epicranial suture gives it a characteristic wedge-shaped appearance. The frontal sutures lie on the dorsum of the head capsule and are so disposed that the *fastigium* (Fig. 1, Fg), the *vertex* (Fig. 2 & 5, VP) and some portion of the dorsal cranium (*parietals*) become included in the frons. The frons is thus dorsallay limited by an imaginary line (Fig. 2, i) drawn from the compound eyes passing under the base of the *antennal socket* (Fig. 1, As) and reaching the vertex.

Two *frontal carinae* (Fig. 1, Fc) originate from the anterior margin of the vertex and extend backward as two more or less parallel and closely approximated ridges running medially through the frons and terminating near the epistomal suture. The frontal carinae enclose a depression formed by the deeply evaginated folds of the cranium in the fronto-medial region and often referred to as the *frontal furrow* (Fig. 1, Ff). The frontal carinae are slightly divulged below the level of the antennal sockets to accommodate the *median ocellus* (Fig. 1, Mo). Below each antenna lies the deeply grooved and transversely disposed *sub-antennal suture* (Fig. 1, S. a. s), internally provided with a ridge.

A suture originating from the epistomal suture and laterad to the frontogenal suture is also slightly discernible, but it is not completely formed. It runs outward and obliquely only for a short distance towards the anterior side where it becomes obliterated. This is the *subocular suture* (Fig. 1, S.o.s).

The frontal carinae divide the facial area of the frons into three unequal parts which are the two *lateral areas* (Fig. 1, La) and a *medial area* or frontal furrow (Fig. 1, Ff). Each lateral area lies between the frontogenal suture of its side and the frontal carina. The medial area, also termed as *frontal costa*, is convex and bounded by the frontal carinae.

c. THE CLYPEUS AND LABRUM (Figs. 1 & 6). The *clypeus* (Fig. 6, CLp) and *labrum* (Fig. 1 & 6, lm) together form a broad free flap called *clypeo-labral lobe*, hanging over the mandibles from the lower edge of the frontal region. The fronto-clypeal or epistomal suture (Fig. 1, E.S) is deeply grooved and internally forms a strong epistomal ridge (fronto-clypeal ridge). On either side of this suture there are *anterior tentorial pits* (Fig. 1, at, frontal pits). These mark the invaginations of the anterior tentorial arms. The epistomal ridge forms brace between the anterior articulations of the mandibles (Fig.1,A. a.m). The clypeus is divided by an ill-defined transverse clypeal suture into an anterior *ante-clypeus* (Fig. 1, A. cl) and a posterior *post-clypeus*. The post-clypeus is further superficially sub-divided into three lobes by means of two small vertical sutures. The two lateral ones are often referred to as *clypealia* (Fig. 1, CLa) and the middle one, which is the biggest, is the *proper clypeus* (p. cl). The clypealia are subtriangular and each laterally bears a *process* (Fig. 1, Pr) to receive the ginglymus of the respective mandible.

The labrum is a broad biconvex plate, medially notched on the anterior side and is slightly asymmetrical, the right half being slightly bigger than the left one. It is capable of free up and down movement along the lower edge of the clypeus and its inner surface is occupied by the *epipharynx*. An angular 'V'-shaped groove with a corresponding internal ridge forms the posterior limits of a well-defined triangular area on the posterior aspect of the labrum. In the lateral angles of the epipharyngeal wall, between the labrum and clypeus, are situated two sickle-shaped sclerotized bars known as the *tormae* (Fig. 6, t). The epipharyngeal surface is equipped with various types of sensillae, brustiae, setae and other sensory hairs. These are asymmetrically disposed to appose the anterior surfaces of the corresponding asymmetrical mandibles. The innermost sensillae are in the form of two rows of thickened bar-shaped pointed hairs (Fig. 6, h) directed towards each other and roughly arranged like a 'V'. Slightly outer to these

are two long rows of finer sensillae, often referred to as brustiae (Fig. 6, Br), covering both the ante-cylpeus and epipharyngeal surface of the labrum. Situated outer to these brustiae are two regularly disposed rows of minute pit-shaped sensillae (Fig. 6, Psn) intermixed with fine brustiae (Fig. 6, Sn). The pit-shaped sensillae are also found scattered along the borders of the epipharynx. Laterad to the the row of pit-shaped sensillae are regular groups of small sensory spines (Fig. 6, Sp) arranged on the epipharyngeal surface. The outer margin of the labrum is limited by a sclerotized ridge. There are a few spinules scattered irregularly along the anterior border of the epipharyngeal surface.

d. THE PARIETALS (Figs. 1, 2, 4 & 5). Anteriorly the parietals are limited by the fronto-genal sutures (FGS) and the imaginary line (i) passing under the bases of the antennae. However, posteriorly the parietals are bounded by the *occipital suture* (Figs. 2 & 4, OCS) and ventrallay by the *subgenal suture* (Fig. 2, Sgs) which is continuous with the more anteriorly disposed epistomal suture (E.S). Each parietal bears an *antenna* (Fig. 1, Ant), a *lateral ocellus* (Fig. 2, Lo) and a *compound eye* (Figs. 1 & 5, CE). The two parietals or epicranial plates are dorsally divided by a longitudinal *coronal suture* (Fig. 5, Cs) disposed dorso-medially. The portion of the parietals just behind the frons and between and behind the compound eyes is termed as the vertex (Figs. 2 & 5, VX). It is, however, not differentiated into a separate sclerite. Anteriorly there is a prominent angle between the vertex and the facial area, often referred to as the fastigium (Fg). Posteriorly, the vertex is cut by the occipital suture into a narrow piece, the *occiput* (Figs. 2 & 4, OC).

Each *compound eye* (CE) is a bean-shaped oval organ surrounded by the ocular suture, which is internally formed into a highly sclerotized ridge (O.R), the *ocular ridge.* The narrow band encircling each compound eye within the ocular suture is known as ocular sclerite. The compound eyes consist of small-sized closely packed hexagonal *ommatidia* (Fig. 1, Om) which present a shining appearance in the living insect.

Each *antenna* (Fig. 1, Ant) is lodged in the *antennal socket* (Fig. 1, As) which is a membranous cavity in the fastigium of its parietal plate. The marginal area of the antennal socket limited by the antennal suture is referred to as the *antennal sclerite* (Fig. 1, Asc).

The portions of the epicranium lying on each side below the

compound eyes and posterior to the frontogenal sutures are called the *genae*. Each gena is thus the lateral region between the compound eye and the base of the mandible of its side and extends posteriorly to the *postoccipital suture* (Fig. 4, POS) and ventrally to the *subgenal suture* (Fig. 2, Sgs). It is separated from the frons by a distinct frontogenal suture. A superficial line divides each gena into two dissimilar *supra-* (Fig. 2, Sgp) and *infra-genal* (Fig. 2, Igp) plates. At the lower angle of the gena a rudimentary *sub-ocular suture* (Fig. 2, S.o.s) is seen meeting the epistomal suture near the anterior articulation of the mandible. Gena is, however, not a definitely demarcated sclerite.

e. THE SUBGENAL AREAS (Fig. 2, Sg). These are two narrow sclerites situated below the subgenal sutures (Sgs). Each of these bears internally a strong ridge, the subgenal ridge. This ridge is some time known as the pleurostoma.

f. THE OCCIPITAL ARCH (Fig. 4). The dorsal and the lateral walls of the head capsule are reflected upon their posterior surfaces to form a horse-shoe shaped band often referred to as the *occipital arch*. This is the area situated between the occipital suture (OCS) and the postoccipital suture (POS). The narrow dorsal surface of the arch corresponding to the vertex (VX) is the occiput (OC) and the lateral areas behind the genae are the postgenae (Pge). Proximally, each postgena bears a cavity which receives the mandibular condyle of its side. The occiput and the postgenae form a continuous sclerite which is also termed as *occipito-postgenal area*. The posterior arms of the tentorium take their origin from the ventral ends of the *postoccipital ridge* (Por) and their points of invagination appear externally as slits, termed as the *posterior tentorial pits* (pt).

g. THE POSTOCCIPUT (Fig. 4, POC). This is a very narrow rim and serves to attach the head capsule with the *cervicum* or *neck membrane*. Anteriorly it is limited by the postoccipital suture (POS). Laterally it bears a condyle termed as *occipital condyle* (O.C). The first cervical sclerite is hinged with this condyle.

h. THE TENTORIUM (Figs. 1, 3, 4 & 7). The tentorium is roughly "X"-shaped and furnishes internal skeleton to the cranium. The *anterior tentorial arms* (Fig. 3 & 7, A.T.A.) take their origin from the anterior tentorial pits (Fig. 1, at) and are directed backwards and inwards and fused with the corpo-tentorium (Figs. 3 & 7, C.T). Anteriorly these are broad and possess thickened margins with an intervening membranous

area. The margins cross over beyond the middle and are considerably narrowed when meeting the corpo-tentorium. The corpo-tentorium is dome-shaped, its dorsal surface being convex and the ventral concave. It serves as a sort of miniature canopy which is braced by four stays. Two of these stays are anterior tentorial arms, already described, and the other two are the *posterior tentorial arms* (Figs. 3 & 7, P.T.A.). The posterior tentorial arms are invaginated from the posterior tentorial pits (Fig. 4, pt) and are directed forwards and inwards to join the corpo-tentorium. The posterior tentorial arms are comparatively short and broad and distally enclose an intervening membrane between the two margins. Near the junction of the anterior tentorial arms with the corpo-tentorium two slender processes are given out which are directed upwards. These are the *dorsal tentorial arms* (Fig. 3, D.T.A.) or *supratentorial arms* (Fig. 7, S.T.A.).

(ii) The Head Appendages

(Figs. 8-18)

a. THE PREORAL CAVITY AND THE MOUTHPARTS. The *preoral cavity* or intergnathal space is well developed in *P. pictus*. This cavity is limited above by the mouth and anteriorly by the epipharyngeal surface of the clypeolabral lobe, its posterior wall is reflected into the adoral wall of the labium and laterally it is limited by the inner faces of the mandibles and the maxillae. A thin membrane forms the innter lining of this cavity and most of the space is occupied by an ovoid lobular hypopharynx. The hypopharynx is suspended from the roof of the preoral cavity and severs as a tongue.

The mouthparts of *P. pictus* are typical mandibulate type. They comprise the *labrum*, the appendages of the gnathal segments, i. e., *mnadibles*, *maxillae* and *labium* together with the *hypopharynx*. Both labrum and the mandibles are asymmetrical and the epipharyngeal surface of the labrum completely fits on the anterior surface of the mandibles.

b. THE HYPOPHARYNX (Figs. 8-10). The *hypopharynx* is subelliptical in shape and bears a small lobe on the ventral side with which the *salivarium* (Fig. 10, Svm) is attached. The dorsal side of the hypopharynx bears two parallel bands of sclerotized areas. These bear sensory hairs (Fig. 8, L.sh) similar in nature to those mentioned in the case of epipharyngeal surface of the labrum. Such sensory hairs are also

present on the lateral side of the hypopharynx. On the postero-lateral side of the hypopharynx are situated two pairs of sclerites disposed in the form of a semi-circle, the pair present more ventrad is that of the *suspensorial sclerites* (Fig 8, S. s), while the one which is more anterior is that of *basal plates* (Figs. 9 & 10, Bp). A transverse sclerite (Fig. 8 & 10, T.S) is situated at the posterior end of hypopharynx, its two arms (labelled 'K' and 'Y' in fig. 10) afford attachment to the adductor muscles of the mandibles and the muscles of the mouth respectively. *Cytopharynx* (Figs. 8 & 9, Cpx) is in the form of an elongate cavity. It is disposed dorso-ventrally and is medially constricted and bordered by a narrowed sclerite. Sensory hairs are also present along the lateral sides of the cytopharynx.

c. THE MANDIBLES (Figs. 1, 3, 11-14). Mandibles are highly sclerotized hollow appendages with a triangular base and thinning out to the cutting margins. Each mandible articulates with the head by means of a *ginglymus* (Figs. 11-14, Gm) and a condyle (Figs. 11-14, Con). The cavity (ginglymus) articulates with a convex *process* of the clypeus and the condyle is a rounded head which fits into a socket at the proximal end of postgena, the fitting in both cases being of ball and socket type. At the base, each mandible is furnished with two apodemes, the larger one is the *adductor apodeme* and the smaller the *abductor apodeme.* These apodemes afford attachment to the adductor and abductor muscles of the mandibles respectively. The two mandibles are asymmetrical, but their entire cutting margins fit admirably upon each other when applied in their natural position. This ensures a very efficient cutting device. The inner edge of each mandible is distally differentiated into an anterior *incisor lobe* (Figs. 11-14, I. L.) and the adjacent posterior *molar lobe* (Figs. 11-14, M. L),

The left mandible (Figs. 13 & 14) is smooth and convex. Its cutting surface is better differentiated on the ventral side and it is furnished with five incisor teeth (in_1-in_5), an additional tooth (Ad. t) and four molar teeth (m_1 - m_4) in their respective areas.

The right mandible (Figs. 11 & 12) is slightly smaller than the left. Its cutting surface, however, is comparatively much better developed, the incisor lobe is somewhat projecting towards the inner side and is constituted by four differently shaped incisor teeth (in_1-in_4), whereas the molar lobe bears a regularly formed concavity with five molar teeth (m_1-m_5).

The postero-medial edge of each mandible (lying between its inner angle and the last molar) is furnished with brush-like fine hairs (Hr) directed medially to form a screen when applied together to prevent the escape of masticated food material from between the jaws. The anterior cutting surface of the right mandible fits appropriately with the corresponding depressed surface of the left mandible, whereas the posterior cutting surface of the right mandile is comparatively compressed and thus amicably receives its counterpart of the left mandible which is considerably bulging out.

d. THE MAXILLAE (Figs. 3, 15 & 16). Each of the two *maxillae* is composed of the usual generalised parts, consisting of the basal stalk and two distal lobes and is implanted (Fig. 3, e) just behind the posterior articulation of the mandible (Fig. 3, P.a.m).

The basal stalk comprises a subtriangular proximal *cardo* (Figs. 15 & 16, Vc, Jc) and a quadrate distal *stipes* (Vs, Js). The cardo or basal sclerite bears a single condyle which is received in a corresponding cavity on the lower side of the postgena. The cardo is separated from the stipes by a well-formed flexible cardo-stipital suture (C.S.S)., internally supported by a strong ridge. Cardo presents an irregular topography on the external surface and is differentiated into a broad outer triangular piece, the *Veracardo* (Vc) and a narrow inner piece, the *juxtacardo* (Jc). These two pieces are separated by a well-formed suture which anteriorly curves to form *Veracardial process* (Vcp). Similarly *stipes* has also been differentiated into two regions, an inner triangular narrow and smaller *juxtastipes* (Js) and the outer rectangular and bigger *verastipes* (Vs). The two sclerites are separted by a suture. The stipes articulates with the distal border of cardo and bears a lateral sclerite, the *palpifer* (pf) , which antero-laterally supports a five-jointed *maxillary palpus* (Mx. p). The terminal segment of the palp is the longest and bears sensory hairs.

Out of the two distal lobes the outer one is the *galea* (Ga, Bg) and the inner one the *lacinia* (Lc). Lacinia is triangular and heavily chitinized. It is situated inner to the galea above the juxta-stipes. The apex of lacinia is differentiated into three well-formed, teeth. It also bears several rows of sensory hairs along its inner edge. Galea lies outer to the lacinia and is a hood-shaped fleshy lobe overlapping the inner lobe (lacinia) and indistinctly divided into a proximal *basigalea* (Bg) and a distal larger *galea proper* (Ga). The basigalea is fleshy

and the galea proper is weakly cuticularized and bears sensory hairs and pit-shaped sensillae which are more numerous towards its distal half.

e. THE LABIUM (Figs. 3 & 17). The labium (Fig. 17) is divided by a slightly angulated emargination of the *labial suture* (Ls) into two primary regions, the proximal *postmentum* (sMt, Mt) and the distal *prementum* (Pmt). The postmentum is further demarcated into two sclerites by means of a transverse suture. The proximal one is the *submentum* (SMt) and the distal one the *mentum* (Mt). Each *palpiger* (Pg) originates near the base of prementum and carries a three-jointed *labial palpus* (Lb. p) of its side. The terminal segment of the palpus is the longest and the basal one the shortest. However, all segments of the palpus are profusely furnished with sensory hairs and pit-shaped sensillae.

Distally the prementum carries an inner pair of triangular asymmetrical glossae somewhat sclerotized ventrally on their inner border. Outer to the glossae are a pair of well developed paraglossae. Each paraglossa is bilobed and medially sclerotized. The ventral surface of the labium is furnished with small bristles and hairs of various types.

f. THE ANTENNAE (Figs. 1 & 18). The *antennae* (Fig. 1,) originate in front of the compound eyes in the *parietals*. Each antennae is lodged in a *socket* (Fig.1, As) surrounded by the *antennary sclerite* (Fig.1,Asc) which is limited by the *antennal suture*. The antennal suture bears a a chitinous process which forms a pivot (Fig. 18, n) for the articulation of antennae and is known as *antennifer*.

The antennae in females are slightly longer than those in males. Typically each antenna consists of a basal *scape* (Fig. 18, Scp) which is much more swollen as compared to other antennary segments. The scape bears a notch proximally by means of which it is articulated to the rim of antennary socket. The articulation between the scape and *pedicel* (Pdc, the next segment of the antenna, which is globular in oultine) is typically of ball and socket type and rests on a membranous cavity on the distal end of the scape. Distally pedicel is equipped with two types of sensillae arranged in two rows parallel to each other. The upper row consists of depressed bigger sensillae, somewhat superimposed on each other and often two layers thick. These have been termed as *Johnston's organs* (Jhn.o). Just below these bigger sensillae, is a single row of regularly disposed sensillae which are spherical in shape.

The second segment of the antenna (pedicel) is followed by the long *flagellum* (FLg) composed of fourteen segments, the terminal segment being the longest. All the segments are profusely furnished with well developed pit-shaped sensillae which are more numerous towards the distal end of the flagellum.

g. THE CERVIX OR NECK REGION (Fig. 19). The *cervix* is a narrow flexible intersegmental region between the head and prothorax. Its true morphological nature is still obscure. However, authors like Snodgrass (1935) and Richards and Davies (1957) consider it to be the remnant of the labial segment and the anterior part of the prothorax, which view has been claimed to be supported by some embryological evidence.

The cervix (or neck) of *P. pictus* is not ordinarilly visible externally because normally this insect keeps its head retracted against the prothorax.

The neck skeleton in the insect under study consists of a pair of lateral *cervical sclerites* embedded in the *cervical membrane* (CM) on either side. The two sclerites of each side are hinged to each other so as to from a sort of bridge between the head and thorax. The first cervical sclerite (1cv) is subtriangular in shape and articulates anteriorly with the *occipital condyle* (O. C) of the head. The second cervical sclerite (2cv) is a narrow rectangular plate and is hinged posteriorly with the prothoracic episternum.

THE THORAX

Snodgrass (1929) and Albrecht (1953, 1956) divide the thoracic region in a grasshopper into anterior prothorax and a posterior pterothorax, the latter being further subdivided into meso- and metathorax. The three thoracic segments are built on a similar structural plan and the difference in the structure of prothorax and pterothorax (meso- and metathorax) is only due to the adaptation of the latter region for the movements of the wings.

Snodgrass (1929) working on *D. carolina* has suggested that the box-like structure of the combined meso- and metathorax, the oblique slants of the pleurites of these segments and the firm connection of first abdominal segment with the metathorax, are characters evidently correlated with the development of the hind legs as saltatorial organs in the case of that insect. The same holds good in explaining the saltatorial adaptation of all jumping grasshoppers including *P. pictus*.

1. The Prothorax

(Figs. 20-22)

The prothorax is a distinctly individualized segment separated from the head and the pterothorax by well-developed intersegmental membranes. The saddle-shaped protergum (pronotum) widely overlaps the mesotergum posteriorly and the propleura laterally.

a. THE PROTERGUM (Fig. 20) The protergum just behind its anterior margin bears a depression (ad) on each of its lateral aspects. This superficial depression on the external side indicates an internal infolding for the attachment of cervical membrane. Thereafter, the protergum is superficially sulcated by three transverse sulci. The first sulcus (C′) is situated just posterior to the depression mentioned above. It is present on the dorsal side and extends a little on the lateral sides. The second sulcus (D′) is situated behind the first and is better developed. It is completely formed on the dorsal as well as the lateral sides. The third sulcus (E′) is situated hindmost and is best developed. It too encircles the protergum dorsally and laterally. On the inner aspect of protergum there are three transverse ridges (C′, D′, E′) which correspond to the aforementioned three sulci. Six oblique ridges (m′, j′, k′, g′, h′, i′) are also present in between these transverse ridges.

The three sulci divide the protergum into four distinct regions or zones. The terminology applied by different authors to designate these regions is in no way similar and hence it is of no consequence in the description of protergum. Some of the earlier workers like Crampton (1918), MacGillivray (1923) and Metcalf & Flint (1932) divide the protergum into a number of subdivisions, viz., prescutum, scutum, scutellum and postscutellum. Also terms like prezona, parazona, interzona and postzona for these subdivisions are attributed to these pioneer workers. Misra (1946) is content to divide the protergum in *S. gregaria* into two regions, an anterior prozona and a posterior postzona. In prozona he includes whole of the area traversed by the three transverse sulci and the postzona includes the posteriorly produced lobe. Hincks (1949), Kevan and Chopard (1954) and Wallace (1955) refer to the corresponding areas as the prozona and metazona respectively. Snodgrass (1935), Imms (1951), Albrecht (1953 & 1956) and Richards & Davies (1957), however, hesitate to ascribe any definite morphological significance to these subdivision of the protargum. They claim that the resulting divisions of the protergum caused by the sutures marked on its surface have no relationship with

those charecteristic of wing-bearing terga, because the differentiation in the wing-bearing terga has resulted on account of the demands for conducting the muscles of flight. Similar "selection pressure" is inevitably wanting in the protergum. Hence, the corresponding subdivisions in the pro- and pterothorax cannot be homologized in a morphological sense. Moreover, none of the ridges mentioned above is sufficiently pronounced to warrant a subdivision of protergum.

In the light of the foregoing discussion about the nature and disposition of the transverse sulci in the protergum, and the fact that different authorities do not agree to attach any morphological significance to the said sulci, it has been considered feasible in *P. pictus* that the area of the protergum anterior to the third sulcus (E′) may be termed as *prozona* (P. Z) and the remaining hood-shaped area posterior to the third sulcus (E′) as *metazona* (M. Z). The metazona is profusely tuberculated with characteristic pit-shaped sensillae some of which are provided with sensory setae. These have been described by Uvarov (1923, 1928) in the case of *S. gregaria* as round *callous tubercles.* (Cst.) Similar sensillae are also found scattered on the anterior as well as lateral borders of the rest of the protergum.

The dorsal surface of the protergum bears the *median carina* which is in continuation with the coronal suture. The median carina has been given different names by different workers. Thus, Richards and Maloff (1954) call it lina media, Uvarov (1928) terms it as median keel, Kirby (1914) describes it as the central carina. The protergum is attached to the mesotergum by means of a membrane referred to as the *intersegmental membrane* (Im).

b. THE PROPLEURA (Figs. 20 & 22) The propleuron is visible externally as a small triangular plate projecting from beneath the lateral edge of the protergum anterior to the base of the proleg. This externally exposed small piece is merely the anterior lower corner of the large triangular *episternum* (Fig. 20, Eps) which extends upwards within the lateral tergal wall anterior to the ridge D′. The *epimeron* (Fig. 20, Epm) is a narrow sclerite which lies concealed underneath the tergum and is not visible externally. The episternum and epimeron are separated by the pleural ridge which internally gives off the *pleural apophysis* (Fig. 20, PLA). This apophysis ventrally ends in the pleural articulation of the coxa. The antero-ventral angle of each episternum is continued through the precoxal bridge (Fig. 22, Acx) with the anterior angle

of the prosternum. The second cervical sclerite (Fig. 22, 2 Cv) is hinged to the margin of the episternum.

c. THE PROSTERNUM (Figs. 21 & 22) The sternum of the prothorax consists mainly of two distinct plates separated by a transverse *furcal suture* (Fig. 22, fs), internally supported by a corresponding ridge that joins the bases of the *prosternal apophyses* (Fig. 21, SA) so as to leave two externally visible *apophyseal pits* (Fig. 22, SAp) laterally. The anterior prosternal plate is larger and better sclerotized and has been termed as *basisternum* (Fig. 21 & 22, BSI) and the posterior, much smaller and less chitinized lobe is spinasternum (Fig. 21, Spn).

The *basisternum* is continuous with the episterna on either side by means of antecoxal bridge (Fig. 22, Acx, precoxal bridge of Albrecht, 1953) and the pleurosternal suture is absent in between the prosternum and the propleuron. The basisternum is limited laterally by the coxal cavity on each side. Anteriorly, it is rimmed with a cuticularized margin termed as the *prosternal strip* or the *presternum* (Fig. 22, PS, prepectus of Snodgrass, 1929). The presternum and the basisternum are separated by the *presternal suture* (P.S.s) bearing an internal ridge. Medially the basisternum is produced into a conical *prosternal process* (Fig. 22, P.s.p) which looks like a peg externally.

The second prosternal plate or *spinasternite* Fig. 21, Spn) is the intersternite between the prothorax and the mesothorax and has become closely associated with the primary sternite (basisternum) of the prothorax. It is mostly overlapped by the anterior margin of the mesosternum.

A membrane articulates the prosternum with the head anteriorly and the mesothorax posteriorly. The anterior membrane is the *cervical membrane* (Fig. 21, Cm) and the posterior one the *intersegmental membrane* (Fig. 22, Im).

ii. The Pterothorax

A. THE PTEROTHORACIC TERGA

a. THE MESOTERGUM (Fig. 23). The mesotergum is a roughly rectangular plate, ending posteriorly in a distinct transvese fold (Rd 2). Each lateral extremity of this fold is continued into a posterior thickened margin or *axillary cord* (Axc) of the respective wing base. Its anterior margin is limited by a narrow triangular intersegmental sclerite, the *precosta* (Pc, acrotergite of Richards and Davies, 1957). The precosta is lined posteriorly by the *antecostal suture* (Acs) and is internally

marked by a pair of large lateral flat plates. Two *prescutal sutures* (Ps), one on each side, diverge from the antecostal suture postero-laterally and mark off on either side the *prescutum* (Psc) from the *scutum* (Sct). The prescutum is split up into two independent lateral halves (Psc) by the interception of the area occupied by the precosta and almost the anterior half of scutum. Each lateral half of the prescutum gets further subdivided into two asymmetrical *prescutal lobes or plates* (LB ^{1}, LB $_2$) lying side by side and running parallel to each other antero-posteriorly. The inner pair of prescutal lobes (LB_1) partly overlaps the area overlying the first pair of thoracic phragmata (1 Ph). The scutum is a broad plate and occupies the major portion of the mesotergum. A pair of well-defined and pigmented oval areas (O.A) are disposed anteriorly on either side of the mid-dorsal line of scutum. Posteriorly a median subrcicular *scutellum* (Scl) and two postero-latera small ovoid areas termed as the *subdivisions of scutum* (sct) are also present.

The posterior deflected margin of the scutellum ends in a narrow intersegmental membrane uniting the mesotergum with the anterior margin of the precosta of the metatergum. The lateral margins of the mesotergum are very irregular and produced into several processes to which the wing bases and the axillary sclerites get articulated. The lateral margin of the prescutal area of each side forms posteriorly a small socket-like articulating surface (n′) for the subcosta vein. Posterior to this socket the scutum is produced to form a large *anterior notal wing process* (ANP) which supports the neck of the first axillary sclerite (1 AX). There is no posterior notal wing process in the mesotergum of *P. pictus*.

b. THE METATERGUM (Fig. 24). The tergal plate of metathorax comparatively longer than the mesotergum as it supports the wider bases of the hind wings. The intersegmental *precosta* (Pc, acrotergite) is narrow and limited posteriorly by the *antecostal suture* (Acs) which is internally produced into a ridge to bear the second pair of thoracic *phragmata* (2Ph). The *prescutal suture* (Ps) is present and the *prescutal areas* (Psc) continue as narrow strips in between the antecostal suture and the scutum.

The *scutum* (Sct) and the *scutellum* (Scl) together constitute a major portion of metatergum. The scutum is divided into two lateral scutal areas with scutellum wedged in between them. The surface features of the scutal and scutallar regions of the metatergum are not so well pronounced as the generalised structure of a wing-bearing tergum. This is because the tergal ridges are almost completely suppressed and some secondary

inflections have occurred in the topographical pattern quite independently of the primary divisions of the tergum. A pair of pigmented oval areas (O.A) similar to, but slightly bigger than, those present in the scutal area of mesotergum are also present in metatergum. Posteriorly, each scutal area is transversely cut by an ill-defined suture. The area lying posterior to this suture is known as the *subdivision of the scutum* (Sct) of the side concerned. The lateral margins of the metatergum present morphological features similar to those of the mesotergum. As in mesotergum the *anterior notal wing process* (ANP) is represented by a flat lobe of the scutum and the postnotal wing process is absent. The slender fourth axillary sclerite (44X) articulates with the posterior angle of the scutellum. Each extremity of the posterior marginal fold of the tergum gives off into the anal membrane of the wing a long arm that supports the anal veins. The posterior marginal area of the metatergum is sharply inflected (Rd3) and is continuous with the greatly extended precosta of the first abdominal segment which constitutes a *postnotal plate* (Fig. 25, PN_3) of the metathorax. The third pair of *phragmata* are situated on the inner aspect of the antecostal suture between the metathorax and the first abdominal segment.

B. THE PTEROTHORACIC PLEURA

(Figs. 25 and 26)

The meso- and metathoracic pleurites are firmly united to form a continuous lateral wall of the pterothoracic region on each side. The pleuron of either side both in meso- and metathorax consists of the anterior *episternum* (Fig. 26, Eps_2 & Eps_3) and the posterior *epimeron* (Figs. 25 & 26, Epm_2, Epm_3) which are distinct plates and are separated from each other by an oblique groove (Fig. 25, PL2, PL3) sloping from above downward and posteriorly. A similar groove known as the *intersegmental groove* (Fig. 26, Isg) separates the meso- from the metapleurites. All these grooves internally bear corresponding ridges respectively known as the *mesopleural ridge* (Fig. 26, PLS_2), the *intersegmental ridge* (Fig. 25, Iss) and the *metapleural ridge* (Fig. 26, PLS_3). Internally the meso- and metapleural ridges each give off at its lower end a large *pleural apophysis* (Fig. 26, PLA2, PLA3) which lies closely associated with the sternal apophysis concerned. The mesoepisternum (Fig. 26, Eps_2) and metaepimeron (Figs. 25 & 26, Epm_3) each terminates above in two large *wing processes* (Figs. 25 & 26, WP2, WP3) and below in the pleural articulation of the coxa. Laterally the pterothoracic pleura of either side are separated from pterosterna by a feebly developed pleurosternal suture (Figs. 25 & 26,

S,S') internally developed into a *pleurosternal ridge*. The ridge in the metapleuron is more conspicuous.

The episternum of the mesothorax (Figs. 25 & 26, Eps_2) is marked near its anterior margin by a submarginal *prepectal suture* (Fig. 25, P. pct. s; presternal suture of Snodgrass, 1929). This suture is continued below through the mesosternum and cuts off from the sternum and the two episterna an anterior marginal sclerite which is termed as *prepectus* (Figs. 25 & 26, P. pct).

The two pairs of thoracic spiracles are located intersegmentally in the pteropleuron, each pair being disposed anteriorly in the segment concerned.

According to Albrecht (1953), in the case of *locusta migratoria*, each episternum is divided into an upper an-episternum and a lower kat-episternum by means of a longitudinally disposed groove (Figs. 25 & 26, v' in meso- and ú in metathorax). In *P. pictus* none of the ridges mentioned is sufficiently developed to warrant a subdivision of the episternum.

C. THE PTEROTHORACIC STERNA

(Figs. 27,28)

The sternal plates of the mesothorax and metathorax are firmly united to form a broad *plastron* covering the ventral surface of the pterothorax. The *pleurosternal suture* in the mesothoracic region lying anterior to the bases of metathoracic coxal cavity (Cxc 3) is faintly marked, but it remains distinct in the metathorax. The median portion of sternellum is wanting in both the meso- and metathoracic sternites. This results in dovetailing of the metasternite into the posterior region of the preceding mesosternite, and likewise of the first abdominal sternum into the metasternite.

a. THE MESOSTERNUM (Figs. 27,28). The mesosternum is a broad plate bounded laterally by a less chitnized *pleurosternal suture* on either side and the rims of coxal cavities (Fig.27, Cxc_2). Anteriorly the mesosternum is slightly convex. A narrow, slender *presternum* (Figs 27 & 28, P. pct, prepectus of Snodgrass, 1929) is cut along its anterior border by the *presternal suture* (Fig. 27 & 28, P.S.s). The posterior border of mesosternum is deeply emarginated to accommodate the elongated rectangular extension of the meta-basisternum (Fig. 27. BS 3) which is dovetailed into the mesosternal notch. A prominent *mesofurcal suture* (Figs. 27 & 28, fs_2) limits the basisternum (BS_2) posteriorly. It forms

internally a ridge through the bases of the *sternal apophyses* (Figs. 27 & 28, SA_2). The sternellum (Fig. 27 & 28, SL2) is cut into a pair of lateral plates (S1,S1) by the suppression of its median counterpart.

The *spinasternum* (Figs. 27 & 28, 2Spn) is much reduced and is fused with the furcal ridge. The spina and the furcal arms are indicated externally as three pits (Fig 27, SAp, Spn).

b. THE METASTERNUM (Figs. 27 & 28). Metasternum is wider than the mesosternum and is separated from the metapleura laterally by a distinct *pleurosternal suture* (Fig. 28, s') on each side. As in mesosternum, the posterior edge in metasternum is broadly emarginated to receive a corresponding extension of the first abdominal sternum. The median *sternellar* region (Figs. 27 & 28, SL3) of metasternum is suppressed in the same manner as in mesosternum. The *furcal suture* (Figs. 27 & 28, fs_3) limits the large *metabasisternum* (BS 3) posteriorly and internally forms a ridge through the bases of the *sternal apophyses* (Fig. 28, SA_3).

A transverse rectangular plate (Figs. 27 & 28, Ss) separated by the *antecostal suture* (Acs) of the first abdominal segment may be considered as the third intersegmental *spinasternite* from which the spina has disappeared.

iii. The Wings

The fore wings (*tegmina*) are elongated, narrow, parchment like and harder in consistency, whereas the hind wings are delicate and membranous ih structure with greatly developed anal area. The latter are the chief organs of flight. As in other grashoppers, the wings of *P. pictus*, during rest, are folded longitudinally with right tegmen slightly overlapped by the left. Typically the wings present three margins; the anterior or *costal margin*, the outer or *apical margin* and the inner or *anal margin*. Three well-defined angles are also recognizable, viz., the *humeral angle* at the base of the costa, *apex* or angle between the costal and outer margins and the *anal angle* or *tormus* between the outer and the inner margins. The angles are better exhibited in the hind wings.

A peculiarity of the tegmen is that the costal margin in the proximal half is curved outwards to form a sharp angular projection (Fig. 29, AP) at the broadest point of the wing.

A. WING VENATION

In describing the wing venation of *P. pictus* the terminology has been adopted from Albrecht (1953) who has described the venation in *Locusta migratoria* by following the recent work of Ragge (unpublished). Wherever possible, this account has been supplemented by the well known nomenclature of Comstock and Needham (1898 and 1899) and Comstock (1918). The usual *archedictyon* pattern which is a characteristic of the wings of Acrididae is also present in the wings of the insect under study.

a. VENATION OF THE FORE WINGS (Fig. 29). In the fore wings *costa* (C) is submarginal followed by the subcosta (Sc). These two veins are united at the base to form a common basal stalk which abuts against the first axillary sclerite (IAX). Both the costa and subcosta are unbranched. In the basal region a small *secondary vein* (s) is present in front of the costa (C). *Radius* (R) and media (M) also arise from a common basal stalk (R+M) and become separated after traversing a little distance. Distally the radius splits up into R_1-R_4 and media gives off MA and MP; MA being further divided into MA_1 and MA_2. There is an *intercalary* (i.c.) present between MA and MP. *Cubitus veins* come next. These are two in number, Cu_1 and Cu_2. Cu_1 terminally bifurcates to give rise to Cu_1a and Cu_1b. The cubitals are followed by the *anal veins* (1A and 2A) which also remain unbranched. The costa, R1, MA, Cu_1 and 1A are *convex*, while the other veins are *concave*.

b. VENATION OF THE HIND WINGS (Fig. 30). Like the fore wings, the *costa* (C) and *subcosta* (Sc) in the hind wings arise from a common basal stalk and remain unbranched throughout their length. The costa is marginal in position. *Radius* is a well developed vein and originates in common with media (M) for some basal portion as R+M. The radius divides terminally into four branches (R_1a, R_1b, Rs_1 and Rs_2). An intercalary vein (i. c.) is present between Rs_1 and Rs_2. *Media* also splits up into its usual components MA and MP. There is also intercalary vein present in between these two branches. Next follow the *cubitus* veins. These are two in number (Cu_1 and Cu_2) and remain unbranched. Cu_2 is not a complete vein and does not reach the margin of the wing. It is followed by a two-plica fold in which the *vena dividens* (V. D) is lodged. The *anal veins* are eight in number, the first anal vein (1A) issues two primary branches (J, K) and each of the

others gives off, near the base, a feebly developed vein which runs anteriorly along the principal vein throughout the length of the wing.

All the anal veins are supported on a common basal stalk (q). The Costa, R_1, MA, Cu_1 and all the principal anal veins are *convex* and Sc, Rs, MP, Cu_2 and feeble branches of the anal veins are *concave*.

B. THE WING ARTICULATION

(Figs. 23-26 and 30)

The articulation of each wing in the case of *P. pictus* is accomplished by three sets of sclerites situated at the notal, basal and pleural surfaces of the thoracic segments concerned and respectively known as *tergal, basal* and *pleural* articulations of the wing.

Dorsally each wing is hinged to the notal wing process which is a small inverted L-shaped sclerite and is articulated to the neck of the first axillary sclerite. The wings also articulate below with *pleural wing processes* (Figs. 25 & 26, Wp_2 and Wp_3). Basally each wing is attached to the body by a membrane, (Fig. 30, a', b') and containing a number of small articular sclerites, split up into two areas collectively known as *pteralia* (Snodgrass, 1939) which include four *axillaries* in each wing base and two *median plates* in the fore wing and one *median plate* in the hind wing. A small oval scale-like flap, the *tegula*, overlaps the base of the fore wing.

Posteriorly the articular membrane at the base of the fore wing is frequently thickened and corrugated to form a ligament-like structure, the *axillary cord* (Fig. 23, Axc) which is continuous with lateral marginal fold of the mesotergum on either side.

The articular sclerites or pteralia of the wing base in a fully stretched wing are as follows:-

a. THE AXILLARY SCLERITES. These are four in number. The *first axillary sclerite* (Figs. 23 & 24, 1AX) is roughly bell-shaped and articulates with the anterior notal wing process (ANP) and second axillary sclerite (Figs. 23,24 & 30, 2AX). Its anterior process gets articulated with the base of subcosta vein. The first axillary sclerite of the hind wing is similar to that of the fore wing with the only difference that its anterior process (neck) is not well developed.

The *second axillary sclerite* (Figs.23,24&30,2AX) is roughly shoe-shaped with its dorsal surface better exposed than in the first axillary sclerite. Its dorsal part, which is approximately triangular, lies close but laterad to the first axilllary sclerite and is hinged to the oblique

outer margin of the latter. The posterior margin of this sclerite articulates with the proximal median plate (Figs.23&24, m_1) towards its anterior end. On its dorso-lateral aspect it is articulated with the base of the radius. It rests through its lower edge against the pleural wing process. The shape of the second axillary sclerite differs in the fore and hind wings as shown in figures 23 and 24. However, in disposition and attachment to the adjoining sclerites, it is similar in both fore and hind wings.

The *third axillary sclerite* (Figs. 23 & 24, 3AX) furnishes attachment to the proximal median plate as well as the second axillary sclerite. Ventrally the third axillary sclerite is disposed in the form of a transverse bar; its proximal end which is hook-shaped provides articulation on the lateral side with fourth axillary sclerite (Figs. 23 & 24, 4AX) while its distal end is connected with the anal veins. The third axillary sclerite in the two wings is more or less similar, with the only difference that it is placed along the longitudinal axis in the fore wing but is disposed along a more vertical axis in the hind wing.

The *fourth axillary sclerite* (Figs. 23 & 24, 4AX) is the smallest and furnishes articulation between third axillary sclerite and the lateral margins of the tergum. According to Snodgrass (1929) it is probably a detached lobe of the tergum, since it is usually absent in insects that have a post-notal wing process. The fourth axillary sclerite in the fore wing of *P. pictus* is like an inverted V, whereas in the hind wing it takes the from of Y.

b. THE MEDIAN PLATES (Figs. 23 & 24, m_1, m_2,) These are two sclerotic plates in the fore wings situated in the median area of each wing base and lie distal to the second axillary sclerites. These are, however, not so definitely differentiated as the principal axillary sclerites. The two plates lie close to each other and are separated obliquely by a suture. The *proximal median plate* (m_1) is attached distally to the third axillary sclerite (3AX) and anteriorly with the posterior margin of the second axillary sclerite (2AX). The *distal median plate* (m_2) supports the bases of media and cubitus veins. The two median plates are so disposed that they help in the flexion of wings. There is only one median plate (m_1) in the hind wing of *P. pictus* and it lies between the second and the third axillary sclerites.

A number of small sclerites, which are derivatives of the pleurites, become intimately associated with the articular mechanism of the wings.

Of these, the two episternal epipleurites are termed as basilares (Fig. 30, Ba_1 and Ba_2) and the epimeral epipleurite as subalare (Fig. 30, Sa_2 and Sa_3). The position and articulation of these epipleurites with adjoining sclerites is exhibited in figures 25, 26 and 30.

iv. The Legs

(Figs. 22, 31-35)

The three pairs of legs are unequally developed. The hind pair is of greater size and is typically adapted for jumping, its femur is enlarged to accommodate powerful muscles.

Each leg constis of a *coxa*, a *trochanter*, a *femur*, a *tibia*, a three segmented *tarsus* together with certain basal articular sclerites and a terminal *pretarsus* comprising a pair of lateral claws-the *ungues* and a median *arolium*. Each leg is set in the *coxal cavity* of the sclerotized body wall between the pleuron and the sternum. The attachment is effected through a membrane called *coxal corium* which lodges the basal articular sclerites.

a. THE COXAE (Figs. 22, 31-33, Cx). The basal articulation of each coxa is effected by the *coxal process* (Fig. 22, Cx. p) of the pleuron and a small basal articular sclerite of the coxa termed as the *trochantin* (Figs. 31 & 32,) which unites with the coxal process. The prothoracic coxa is most freely movable and is projected downwards. The mesothoracic coxa is directed downwards and posteriorly; its base lies in an oblique plane between the pleuron and the sternum. The metathoracic coxa is directed posteriorly; its base is on the inner side and lies in an approximately vertical plane.

Each coxa presents a well-marked basal rim, or *basicoxite*, set off by a submarginal *basicostal suture* (Figs. 31-33, Bcs) internally produced into a corresponding ridge, the *basicosta*. The basicoxite is very narrow or obsolete on the mesal surface of the coxa, but on the outer lateral surface it is developed into a distinct articular lobe termed as the *meron* (Fig. 32, Mer). Each coxa is attached by a dicondylic hinge to the trochanter.

The anterior wall of the prothoracic coxa medially bears a *coxal suture* (Figs. 31 & 32,) which extends from the anterior trochanteral articulation to the basicostal suture at the articulation of the trochantin. The mesothoracic coxa also bears a similar suture which extends from

the trochanteral articulation to the pleural articulation. The coxal suture is absent in the coxa of the metathoracic leg. On the prothoracic coxa a well developed and slighly recurved coxal spine (Cx. s) is present which is better discernible on the ventral surface of the coxa.

b. THE TROCHANTERS (Figs. 31-33, Tr). The trochanter is a short-sized segment in each leg; it has a dicondylic hinge with the coxa on one side and is rigidly connected with the femur on the other.

c. THE FEMORA (Figs. 31-33, Fm). The femur forms the longest segment of the leg. In the pro- and the meso-leg it is a simple elongated segment, somewhat flattened antero-posteriorly. The distal end of each femur is laterally expanded into broad lobes that conceal a portion of the femoro-tibial joint and bears a deep elliptical groove provided with articular membrane to allow a free flexion of the tibia beneath the femur.

The femur of the metaleg (Fig. 33) is best developed becsuse it contains principal fish-bone shaped leaping muscles. All along its ventral surface it is deeply grooved to accommodate the tibia when needed. This ventral groove is the *femasulcus* and bears a peg-like Brunner's organ at at its proximal end. As stated by Silifer and Uvarov (1938), vide Albrecht (1953), the Brunner's organ is a sensory oragan. Distally the hind femora bear strongly sclerotized semilunar plates (Sm. p) on the lateral sides. On the inner side of each hind femur is a longitudinal ridge termed as the *stridulatory crest* which bears many small peg-like tubercles for stridulation by rubbing them against the thickened radius vein of the tegmen. These tubercles are better pronounced in the male than in the female.

d. THE TIBIAE (Figs. 29-31, Tb). Each tibia is a slender segment of the leg, and is slightly shorter in length than the femur in all the three legs. The femoro-tibial articulation is a strong dicondylic hinge. Each one ef the pro- and meso-tibiae on its distal half is furnished ventrally with five pairs of hollow spinules (Spl) disposed in two more or less parallel rows. The tibia of metaleg on the two dorso-lateral margins bears 7-9 pairs of well formed hollow *spinules* (Spl) which are similar in arrangement to those occurring on the pro- & meso-tibiae. In addition, two pairs of *spines* (Sp) are situated a pair each on the two lateral aspects of the distal end of tibia.

e. THE TARSI (Figs. 31-33, Tar, p. Tar). Each tarsus is composed of three subsegments. The large basal subsegment bears three pairs of

pads on the underside which are pulvillus-like organs or *plantulae* (Figs. 31-33, PLt). The middle subsegment has a single pair of these organs and the slender terminal segment is devoid of such pads.

The terminal segment in each leg consists of a pair of large lateral claws, the ungues (Un), and a proxomedially placed lobe the *arolium* (Ar). On the ventral side, the pretarsus is provided with two sclerites, the proximal sclerite is termed the *unguitractor plate* (Figs. 34-35, Utr), and the distal one, possibly a subdivision of the unguitractor plate, is the *planta* (Fig. 35 Pln). Dorsally a sclerotized area, the *unguifer* (Fig. 35 Uf) connects the two claws.

THE ABDOMEM

As in other grasshoppers, the abdomen is the largest region of the body in *P. pictus*. It is composed of eleven segments. The abdominal segments are simple and annular in form for the most part and their terga and sterna are undivided shields while the pleura are membranous.

The structure of the abdomen may conveniently be described under the following three headings:—

i. General structure; ii. The Ovipositor and iii. The Male Genitalia.

i. General Structure

(Figs. 36-40)

The abdomen of P. *pictus* is broadly united to the matathorax through the dorsal and the sternal segmental sclerites. The sclerotized parts of the abdominal integument take the form of tergal and sternal segmental plates, separated by membranous areas on the sides. The intersegmental membranous fold of the first abdominal segment internally forms a submarginal antecosta on the tergal and sternal plates and is marked externally by the corresponding antecostal suture (Figs. 36-40, Acs). The terga and sterna that follow bear no sutural division.

For the sake of simplicity, it is convenient to discuss the abdomen under the following divisions, viz., pregenital or visceral segments (1-7 in female and 1-8 in male); genital segments (8th and 9th in female and only 9th in male); and postgenital segments (10th and 11th).

a. PREGENITAL OR VISCERAL SEGMENTS (Figs. 36-37). The posterior margin of each preceding tergum and sternum overlaps the anterior margin of each such succeeding sclerite. The terga and sterna are joined through lateral membranes so as to provide vertical respiratory movements.

The first abdominal segment is the largest and, as described already, is broadly joined to the metathorax. The antecosta of the first abdominal tergum bears the third pair of *phragmata* and the *precosta* (Fig. 36, Psc, acrotergite) is much enlarged to form the *postnatal plate* (Fig. 36, PN3) of the metathorax. Ventrally the first abdominal sternum apparently forms a part of the metathoracic plastron. However, a closer examination reveals that the *antecostal suture* of the first abdominal sternum separates out a small rectangular plate in front which is the third intersegmental *spinasternite* (Fig. 40, Ss) from which the spina has disappeared. As in other acridids, the first abdominal segment in *P. pictus* bears a large membranous oval cuticularized area on either side. This is known as the *tympanal organ* (Fig. 36, Tm). Each tympanal organ on its anterior side bears a slit-like depression which lodges the first addominal spiracle of the side concerned.

Like other members of the subfamily Pyrgomorphinae, a large bi-lobed sac-like dorsal gland is also present in *P. pictus* in the first abdominal tergite. It traverses the whole length of the first tergite and opens in the membrane between this and the second tergite. A fluid is ejected with some force from this opening when needed. Similar structures in the thorax of other grasshoppers have been recorded by Uvarov (1928), Beier (1937), Jannone (1938, 1939) and, according to Uvarov (1948), by Miller (1935).

The remaining pregenital segments (2-8 in male and 2-7 in female) are built on a similar morphological plan and bear no sutural division on the dorsal and ventral sides. Typically each of these segments is annular in shape with a pair of spiracles located on the lower lateral sides. On the ventral aspect a pair of *sternal apodemes* (S. Apd) is provided internally on the antero-lateral margins of each of these segments. Such apodemes are also present on the eighth and ninth abdominal sterna of the genital segments in the female.

The tergites of the pregenital segments one to seven each bears a pigmented *oval area* (Fig. 36, O.A) disposed on either side of the mid-dorsal line. Similar areas have also been described on the moso- and metathoracic tergites. According to Silifer (1951) and Albrecht (1953, 56), these are sensory organs capable of perceiving changes in the radiant heat to which the insect is subjected.

b. GENITAL SEGMENTS (Figs. 38-40). Segment 9th in the male and

segments 8th and 9th in the female show some structural adaptation to the genital functions.

In female the 8th segment is similar to the preceding segments and constitutes the last visible sternum which forms a broad squarish plate, known as the *subgenital plate* (Sgp; gynatrium of Gupta, 1948). It is produced posteriorly behind the limits of its tergum and terminally bears two lateral and one median lobe. The median lobe is triangular and projects in between the bases of ventral valves of the ovipositor and has been termed as the *egg-guide* (Fig. 39, E.g; Qadri, 1940; Albrecht, 1953). The ninth segment is narrow and partially fused with adjoining segments. The dorsal pair of valves is derived from the eight abdominal segment and the posterior and anterior pairs from the ninth segment.

In male the ninth segment is narrow and constitutes the last visible sternum which is formed into a boat-shaped *subgenital plate* (Figs. 38-39, Sgp) to accommodate the genital organs internally.

c. POSTGENITAL SEGMENTS (Fig. 38-40). The tenth abdominal segment is reduced and more or less united with the 11th segment posteriorly. Its tergum is represented by a triangluar plate which is fused with epiproct to form a composite *supra-anal plate* (Fig. 38, S. ap, suranal plate of Richards and Davies, 1957). The ventral part of the 10th segment is represented by a membranous area and does not appear as definitly distinct segmental region.

The eleventh segment forms a conical end piece of the body, bearing unsegmented *cerci* (Fig. 38, Cer) laterally and the *anus* dorsally. The dorsal surface is covered by a triangular plate the *epiproct* (Figs. 37 & 38, Ep. pt). The two lobes known as the *paraprocts* (Figs. 37 & 38, Pa. pt) are formed on the ventro-lateral aspects of this segment. The cerci are implanted in the membranous area between the bases of the epiproct and the paraprocts behind the tenth tergum. Their connection with the tenth segment becomes more pronounced with the reduction of the eleventh segment.

ii. The Ovipositor

(Figs. 41 & 42)

The ovipositor consists of a *dorsal* or *lateral pair of valves* (3 VI), a *posterior* or *inner air of valves* (2 VI) and an *anterior* or *ventral pair of valves* (1 VI). As already stated, the dorsal pair of valves is derived from the eighth abdominal segment, while the posterior and the anterior pairs

originate from the ninth abdominal segment. The inner pair of valves is small and concealed and presents the shape of a two-pronged fork. The dorsal and ventral pairs of valves are strengthened by an *intersegmental apodeme* (I. Apd; the process of intersegmental apophyses of Walker, 1919), dorsal and ventral lips of the apodemes (a, b), small sclerites at the base of the apodeme (d, t'), intervalvular plates (Fig. 42, Aiv, Piv) and the small apodeme-bearing sclerite (Fig. 42, e').

iii. The Male Genitalia

(Figs. 43 - 45)

Extensive work has been done on the male genitalia and, as suggested by a number of authors, this structure froms a significant basis for establishing inter-relationships between different insect groups. A very extensive treatment of this subject has been attempted recently by Dirsh (1956) on the phallic complex in Acridoidea. The detailed morphological nature of the work renders it extremely valuable for taxonomic purposes. As many as six dozen terms have been used by him to describe the genital complex of the group referred to above. In describing the genitalia of *P. pictus*, therefore, the same terminology has been followed, but only the salient features have been incorporated here. The male genitalia can be conveniently discussed as comprising the phallic organ or phallus and the epiphallus.

a. THE PHALLIC ORGAN OR PHALLUS (Figs. 43 - 45) The organ concerned with the accumulation of sperms and their transmission to the female genital chamber is termed as *phallic organ* or *phallus*. The structure of the phallic organ in the insect under study is rather complicated. It consists of the ecto- and endophallus. The ectophallus is differentiated into an outer ectophallic membrane and a sclerotized cingulum. The *ectophallic membrane* (Figs. 43 & 44, Ect. m) is thin and partly covers the phallic organ. It is connected with the rami of the cingulum (Figs. 43 & 44, Rm. cn) on the lateral and ventral sides. A membranous continuation of the chamber partly covers the apex of the phallus when not erected.

The *cingulum* (Fig. 44, cn) is strongly sclerotized and consists of a pair of elongated sclerotized *apodemes* (Figs. 43 & 44, Apd) which are joined together at their proximal ends by a broad transverse bar known as *zygoma* (Fig. 44, Zm). The rami (Figs. 43 & 44, Rm. cn) are fused ventrally to form, together with the zygoma and the apodeme, a capsule-like covering to the apical part of the endophallus. The extensions of

rami cover the apical part of the penis and are called the *sheath* (Fig. 43, Sh). On the ventral side of the cingulum the extension of the rami also bear a pair of *ventral valves* (Figs. 43 & 44, C. V) which are parallel to the apical valves of penis.

The endophallus is represented by a pair of undivided valves of penis-proximally the *basal valves* (Figs. 43 & 44, B. pen) and distally the *apical valves* (Figs. 43 & 44, A. Pen). The proximal valves widen laterally to form rounded ends and the apical valves are upcurved with acute apices. The median part between the valves is robust and strongly thickened.

The *ejaculatory duct* (Fig. 43, Dej) reaches the middle of the valves of penis. The distal continuation of the duct is strongly widened to form *ejaculatory sac* (Fig. 43, Dej. S) which occupies ventral position. On the distal end there is a moderately long slit-like ventral opening known as *phallotreme* (Fig. 43, Pht). The edges of the ventral slit-like opening are continuous with the ectophallic membrane and form the *phallotremic cleft* (Fig. 43, Ph. cl).

b. THE EPIPHALLUS (Fig. 45). Recently, Dirsh (1956) has invited the attention of systematists to the morphological significance of epiphallic complex in the classification of Acridoidea. He has revised entirely the classification of the said group in the light of the structure of this sclerite. Therefore, this sclerite needs to be studied more thoroughly than any other component of the genitalia so far described.

Snodgrass (1935) describes epiphallus as a sclerite in some Orthoptera in the floor of the genital chamber proximal to the base of the phallus. Albrecht (1953) states that epiphallus is a complicated structure which is formed by a series of sclerites attached the basal folds of the dorsal valves. Dirsh (*loc. cit*) describes epiphallus to be a rather isolated sclerite which is strongly sclerotized and located on the dorsal side of the phallic complex.

The *Epiphallus* (Eph) in the insect under study lies dorso-proximally to the phallic organ. It is a bridge-shaped robust sclerite which is derived from the ectophallic membrane. The epiphallus comprises a pair of *lateral plates* (Lp) which are elongated sclerites with their strong *posterior projections* (Pp) forming strongly upcurved hooks. The two lateral plates unite antero-medially to form a *bridge* (B) overlying the phallic organ. The epiphallus of *P. pictus* also bears *dorso-lateral*

appendices (DA) which are basally united with the main body of epiphallus. The anterior margin of the epiphallus is projected from the middle and is known as the *median projection* (Mp).

SUMMARY

The external anatomy of *Poecilocerus pictus* (Fb.) has been described in detail.

The head of *P. pictus* is of hypognathous type and preserves the acridine orientation. The head capsule is constituted by the frons, the clypeus, the labrum, the parietals, the subgenal area, the occipital arch and the postocciput. A well developed tentorium furnishes the internal skeleton of the head capsule. The epicranial suture is atypical in being arrow-shaped anteriorly. An incomplete suture is present outer to the frontal genal suture. The cephalic appendages are typically Orthopteroid in structure.

The basic structural plan of the three segments of the thorax is of the generalized type. The anatomical differences exhibited by the pro- and the pterothorax, however, are of adaptive nature and those of the latter part have evidently been developed in response to the articulation mechanism of the wing. A detailed description of the tergites, pleurites and the sternites of the pro-, meso- and metathoracic segments has been given.

As in other grasshoppers, the abdomen of *P. pictus* is the largest region of the body and is composed of eleven segments. The first abdominal segment is the largest and broadly joined to the metathorax. It bears large membranous oval tympanal organs and a bilobed sac-like dorsal gland in the tergite which traverses the whole length and opens in the membrane between it and the second tergite. The first eight abdominal segments bear a pair of spiracles each on the lateral sides. In addition, the pregenital segments bear a pigmented oval area disposed on either side of the mid-dorsal line. A pair of sternal apodemes is present internally on the antero-lateral margins of segments 1-8 in the female and 1-9 in the male. A comprehensive account of of the ovipositor and male genitalia with special reference to the phallic complex as a taxonomic character in classification of Acridoidea has been given. Also the phallic organ and the epiphallus have been described in detail.

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LIST OF FIGURES

Figure 1. Head (Front view).
Figure 2. Head (Lateral view, External).
Figure 3. Head (Lateral view, Internal).
Figure 4. Head (Posterior view).
Figure 5. External view of head (Dorsal view).
Figure 6. Epipharyngeal surface of clypeus and labrum (Inner aspect).
Figure 7. Tentorium.
Figure 8. Hypopharynx (Dorsal view).
Figure 9. Hypopharynx (Antero-dorsal view).
Figure 10. Hypopharynx (Lateral view).
Figure 11. Right mandible (Dorsal view).
Figure 12. Right mandible (Ventral view).
Figure 13. Left mandible (Dorsal view).
Figure 14. Left mandible (Ventral view).
Figure 15. Right maxilla (Dorsal view).
Figure 16. Left maxilla (Dorsal view).
Figure 17. Labium (Dorsal view).
Figure 18. Right antenna (Dorsal aspect).
Figure 19. Prosternum (Internal view).
Figure 20. Prothorax (Right half bisected).
Figure 21. Prosternum (Internal view).
Figure 22. Prosternum (Ventral view).
Figure 23. Mesothoracic Tergum (Dorsal aspect).
Figure 24. Metathoracic Tergum (Dorsal aspect).
Figure 25. Left Pterothoracic Pleura (External view).
Figure 26. Right Pterothoracic Pleura (Internal veiw).
Figure 27. Pterothoracic Sterna (Ventral view).
Figure 28. Pterothoracic Sterna (Internal veiw).
Figure 29. Right Fore and Hind Wings (Dorsal aspect).
Figure 30. Wing Articulation (Ventro-lateral view).

Figure 31. Right Fore leg (Lateral view).
Figure 32. Right Meso leg (Lateral view).
Figure 33. Right Meta leg (Lateral view).
Figure 34. Tarsus of Proleg (Ventral aspect).
Figure 35. Tarsus of Meta leg (Lateral aspect).
Figure 36. Abdomen (Lateral aspect).
Figure 37. Tip of abdomen, Male and Female (Dorsal view).
Figure 38. Tip of abdomen, Male and Female (Lateral view).
Figure 39. Tip of abdomen, Male and Female (Ventral view).
Figure 40. Female abdomen (Internal aspect).
Figure 41. Ovipositor (Lateral veiw).
Figure 42. Ovipositor (Posterior view).
Figure 43. Aedeagal complex (Dorsal view).
Figure 44. Aedeagal complex (Ventral view).
Figure 45. Epiphallus (Dorsal view).

LIST OF ABBREVIATIONS

a	dorsal lip of apodeme
a'	membranous area at the base of fore wing
1A - 8A	anal veins
A.a.m	anterior articulation of the mandible
A.cl	ante-clypeus
Acs	antecostal suture
Acx	precoxal bridge
ad	lateral depression of protergum
Ad.t	additional tooth
Aiv	anterior intervalvula
ANP	anterior notal wing process
Ant	antennae
AP	angular projection of the fore wing
Apd	apodeme of the cingulum
A.Pen	apical valves of penis
Ar	arolium
As	antennal socket
Asc	antennal sclerite
at	anterior tentorial pit
A.T.A.	anterior tentorial arm
1Ax-4Ax	axillary sclerites
Axc	axillary cord
B	bridge of epiphallus

b	ventral lip of apodeme
b′	membranous area at the base of the fore & hind wing
Ba′	first basalare
Ba_2	second basalare
Bcs	basicostal suture
Bg	basigalea
Bp	basal plate
B.Pen	basal valves of penis
Br	brustae
BS_1, BS_2, BS_3,	basistermum
C	costa
C′	transverse sulcus of prothorax
CE	compound eye
Cep	clypeus
Cer	cercus
CLa	clypealia
Cm	cervical membrane
Cn	cingulum
Con	condyle
Cpx	cytopharynx
Cs	coronal suture
Cst	callous tubercles
C.T.	corpo-tentorium
Cu_1	first cubitus
Cu_2	second cubitus
Cu_1a. Cu_1b	branches of first cubital vein
C.V	ventral valves of cingulum
Cv1, Cv2	cervical sclerites
1cv	first cervical scterite
2cv	second cevrical sclerite
Cx	coxa
Cxc_2, Cxc_3	coxal cavities
Cxp,	coxal process
CXs,	coxal spine
Cxs	coxal suture
d	small sclerite at the base of apodeme
DA	dorso lateral appendices of epiphallus
D′,E′	transverse suture of prothorax
Dej	ejaculatory duct
Dej, S	ejaculatory sac
D.T.A.	dorsal tentorial arm

c′	apodeme-bearing sclerite
EcEm	ectophallic membrane
E.g	egg - guide
Eph	epiphallus
Epm	proepimeron
Epm_2	mesoepimeron
Epm_3	metaepimeron
Ep.pt	epiproct
EpS	proepisternum
EpS_2	mesoepisternum
EpS_3	metaepisternum
E.S	epistomal suture
Fc	frontal carine
Ff	frontal furrow
Fg	fastigium
FGS	frontogenal suture
Flg	flagellum
Fm	femur
For	occipital foramen
Fr	frons
FS	frontal suture
fs	profurcal suture
fs_2	mesofurcal suture
fs_3	metafurcal suture
Ga	galea proper
ge	gena
g′h′i′	oblique ridges of pronotum
Gm	ginglymus
h	hairs
i	imaginary line
I.Apd	intersegmental apodeme
i.c.	intercalary vein
Igp	infra-genal plate
I.L.	incisor lobe
Im	intersegmental membrane between pro- and pterothorax
in_1-in_5	incisor teeth
Isg	intersegmental groove
Iss	intersegmental ridge between meso- and metathoracic pleura
I.v.p_1-I.v.p_3	intervalvular plates
J	primary branch of first anal vein

j′	oblique ridge of pronotum
Jc	juxtacardo
Jhn.O.	johnson organs
Js	juxta stipe
K	primary branch of first anal
k′	oblique ridge of pronotum
La	lateral area
LB1,LB2	prescutal plates or lobes
Lb.p	labial palpus
Lc	lacinia
Lm	labrum
Lo	lateral ocellus
Lp	lateral plate
Ls	labial suture
L. sh	lateral sensory hairs
M	media
m′	oblique ridge of pronotum
m_1,m_2	median plates of wing base
m_1,m_4	molar teeth
MA,MA_1,MA_2	branches of media vein
Mer	meron
M.L.	molar lobe
M.O.	median ocellus
MP	branch of media vein
Mp	median projection of epiphallus
Mt	mentum
Mx.p.	maxillary palpus
M.z	metazona
n	antennifer
n′	articulating surface of subcosta vein
O.A	pigmented oval area
O.A	oval area
OC	occipit
O.C.	occipital condyle
OCS	occipital suture
Om	ommatidia
'дam.	posterior articulation of the mandible
Pa.pt	paraproct
Pc	precosta

P.cl	proper clypeus
Pdc	pedicel
pf	palpifer
Pg	palpiger
Pge	postgena
1Ph,2Ph	phragmata
3Ph	third thoracic phragma
Ph.cl	phallotremic cleft
Pht	phallotreme
Piv	posterior intervalvula
PL2	mesothoracic pleural groove
PL3	metathoracic pleural groove
PLA	pleural apophysis
PLA2,PLA3	meso- and metapleural apophyses
PLn	planta
PLS_2	mesopleural suture
PLS_3	metapleural suture
PLt	plantulae
Pmt	prementum
PN_3	lateral arm of metathoracic postnotum
POC	postocciput
PoR	postoccipital ridge
POS	postoccipital suture
Pp	posterior projection of epiphallus
P.pct	prepectus
P.pcts	prepectal suture
Pr	process of the clypeus
PS	presternum
Ps	prescutal suture
Psc	prescutum
Psn	pit-shaped sensillae
P.S.p.	prosternal process
P.S.s	presternal suture
pt.	posterior tentorial pit
P.T.A.	posterior tentorial arm
P.Tar.	pretarsus
P.Z.	prozona
q	basal support of anal veins
R	radius
R_1-R_4,R1a,R1b	branches of radius vein

Rd_2,Rd_3	marginal inflections of meso- & metanotum
Rs,Rs_1,Rs_2	branches of radius vein
r	mesothoracic pleuro-sternal suture
r′	metathoracic pleuro, sternal suture
R&M	united basal shaft of radius and media
Rm.cn	ramus of the cingulum
S	sundery vein
S,S′	meso- and metapleurosternal sutures
SA	prosternal apophysis
SA_2	mesosternal apophysis
SA_3	metasternal apophysis
Sa_2	mesothoracic subalare
Sa_3	metathoracic subalare
S.ap	supra-anal plate
S.Ap	sternal apophyseal pit
S.Apd	sternal apodeme
S.a.s.	sub-antennal suture
Sc	subcosta
Scl	scutellum
Scp	scape
Sct	scutum
Sct	subdivision of scutum
Sg	subgenal area
Sgp	supragenal plate
Sgp	subgenital plate
Sgs	subgenal suture
Sh	sheath
Sl	lateral plates of sternellum
SL_2	sternellar region of mesosternum
SL_3	sternellar region of mesosternum
Sm.p	semilunar process
SMt	postmentum
SMt	submentum
Sn	fine brustiae
S.o.s.	subocular suture
Sp	sensory spine
Sp	tibial spine
Spl	tibial spinules
Spl_1	first abdominal spiracle
Spn	spinasternum

2Spn	spinasternum of the mesosternum
2Spr	mesothoracic spiracle
Ss	spenasternite
St-St	abdominal sterna
S.T.A.	supratentorial arm
Svm	salivaruim
t	torinae
t'IX	small sclerite at the base of apodeme
Tar	tarsus
Tb.	tibia
Tg-Tg	abdominal terga
TmXI	tympanal organ
Tn	trochanter
T.S.	transverse sclerite
u'	longitudinal groove of episterna
uf	unguifer
Un	ungues
Utr	unguitractor plate
v'	longitudinal groove of episterna
1VI-3VI	ventral, posterior & dorsal pair of valves
Vc	veracardo
V.D	vena dividens
Vep-	veracardial process
Vs	verastipe
VX	vertex
WP_2, WP_4	wing processes
Zm	zygoma

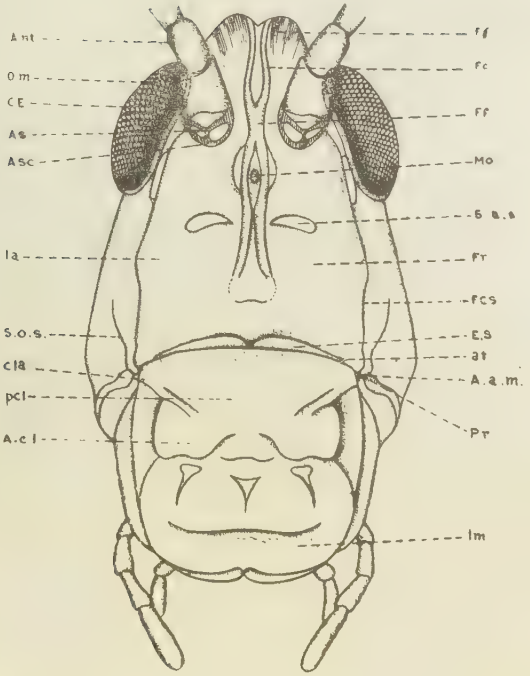
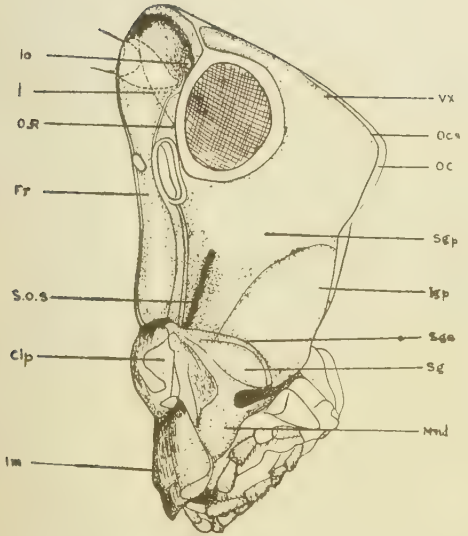


Fig. 1



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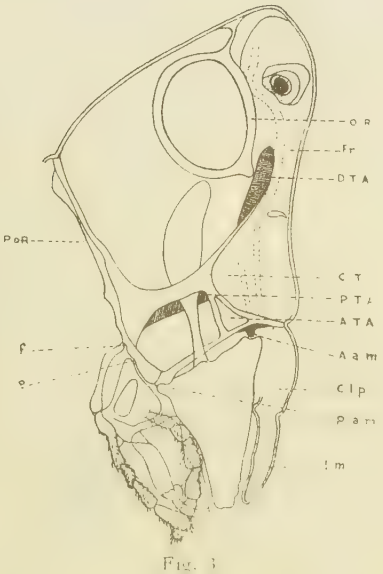

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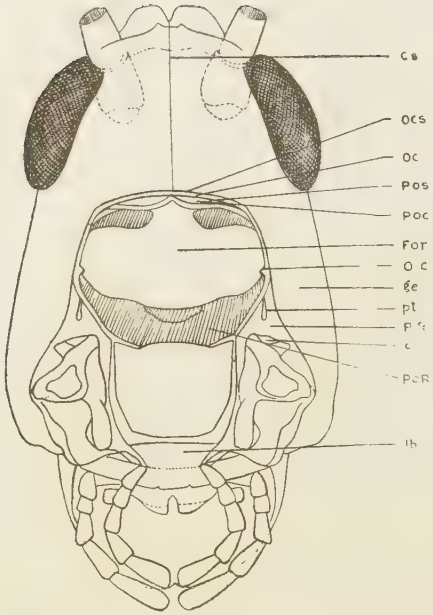

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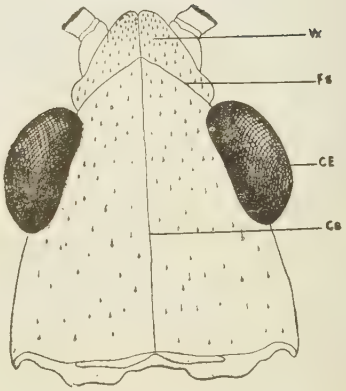

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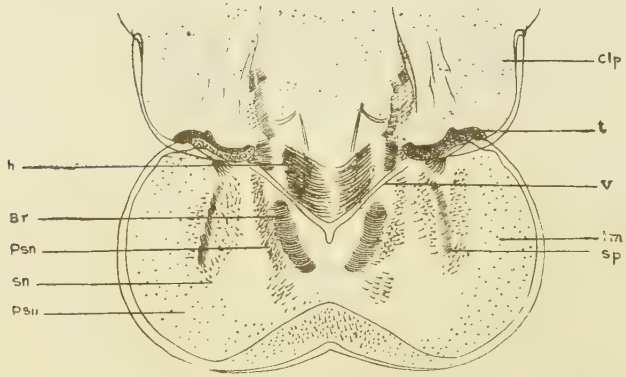
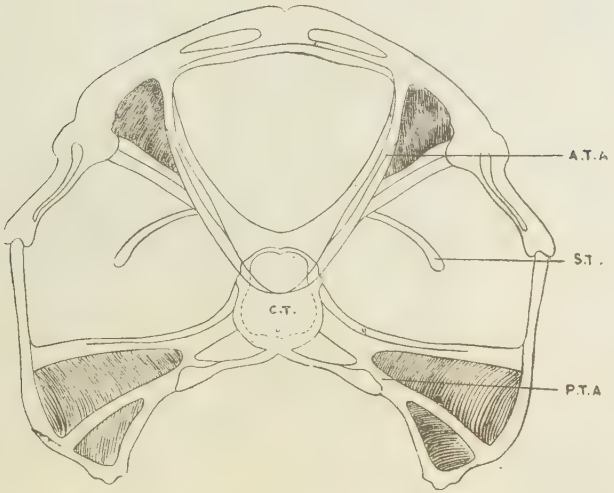
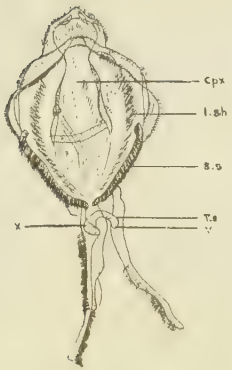
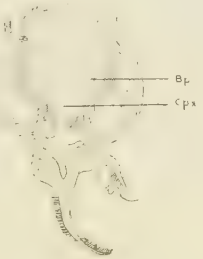


Fig. 6

Fig. 7







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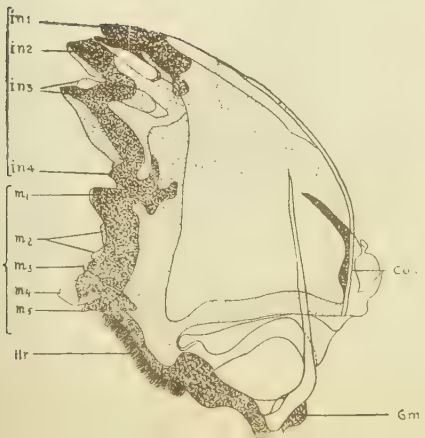

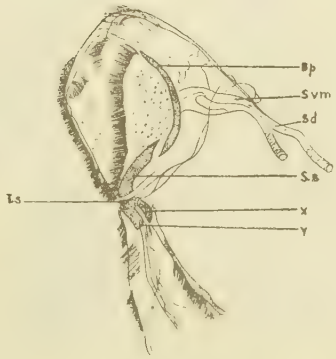

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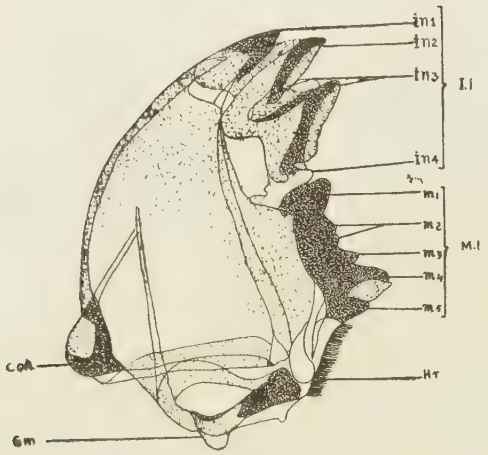
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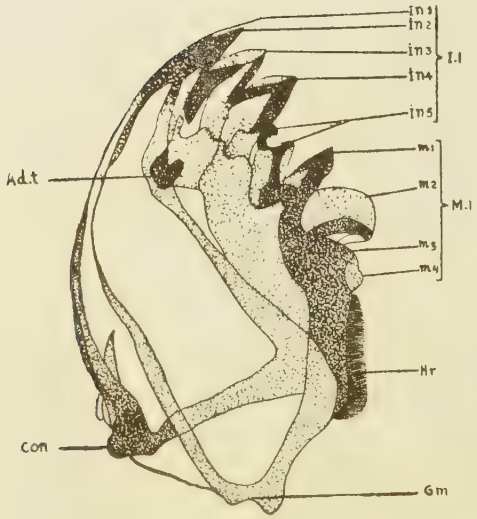
m2
m3
M.1
m4
m5
Hr
Gm

Fig. 12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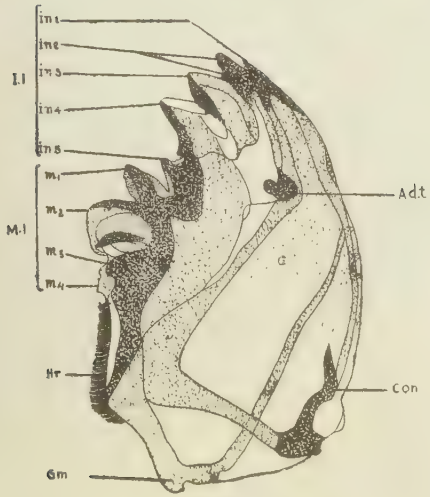
in2
in3
I.1
in4
in5
m1
Add
m2
M.1
m3
m4
Hr
Gm

Fig. 13



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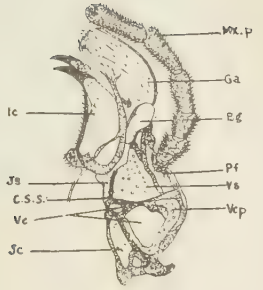

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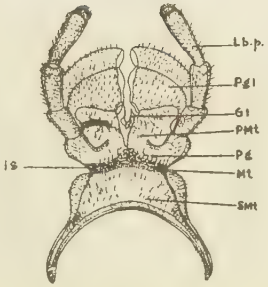

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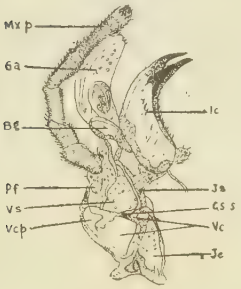

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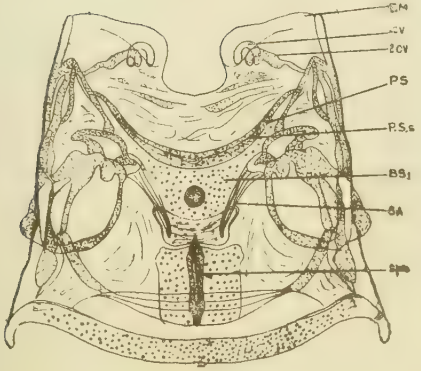

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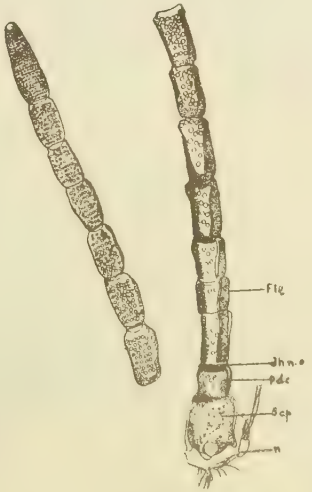

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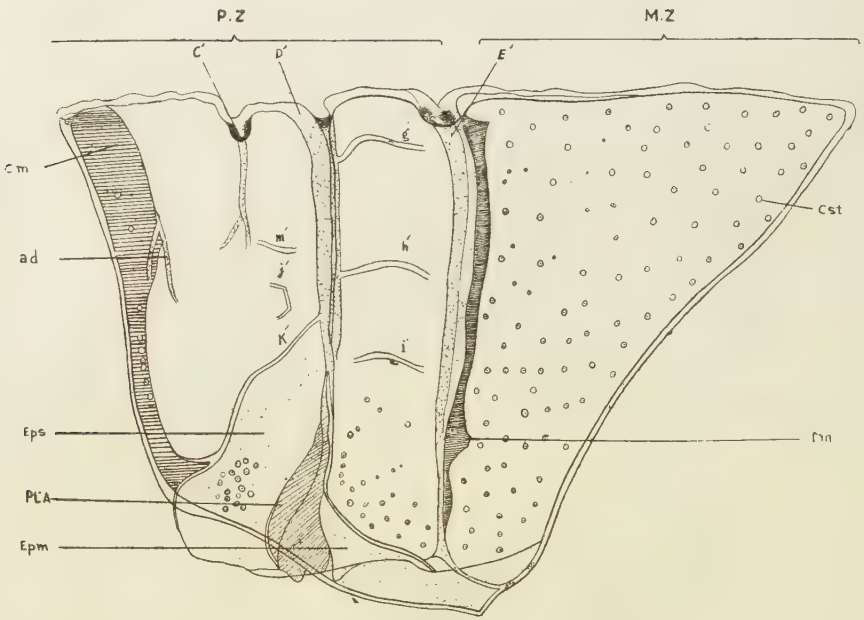

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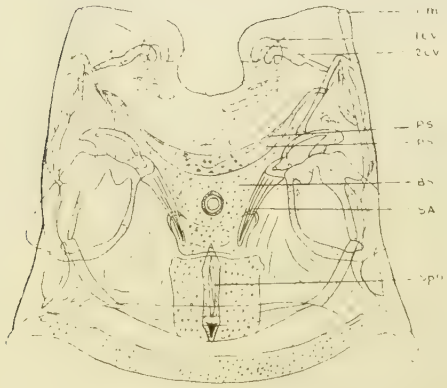

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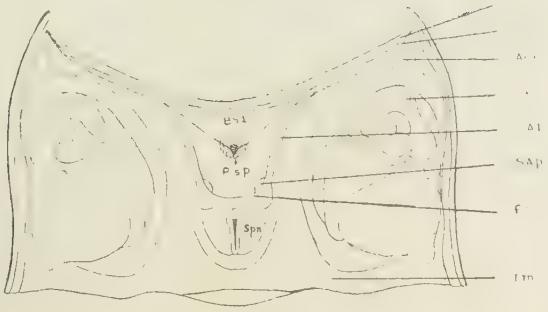

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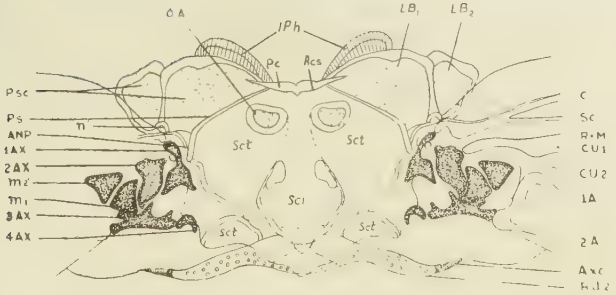

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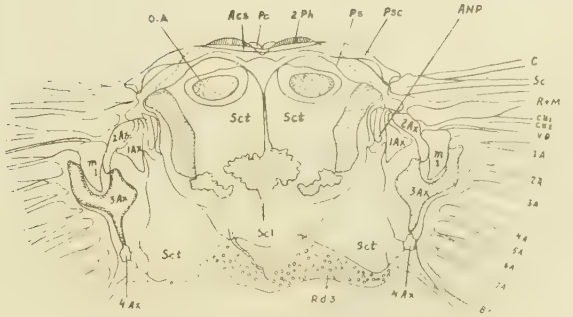

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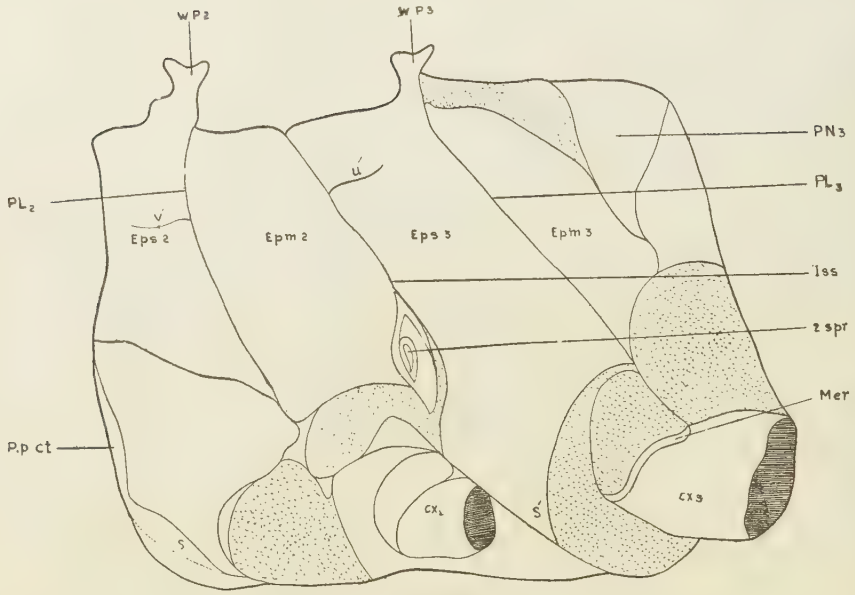
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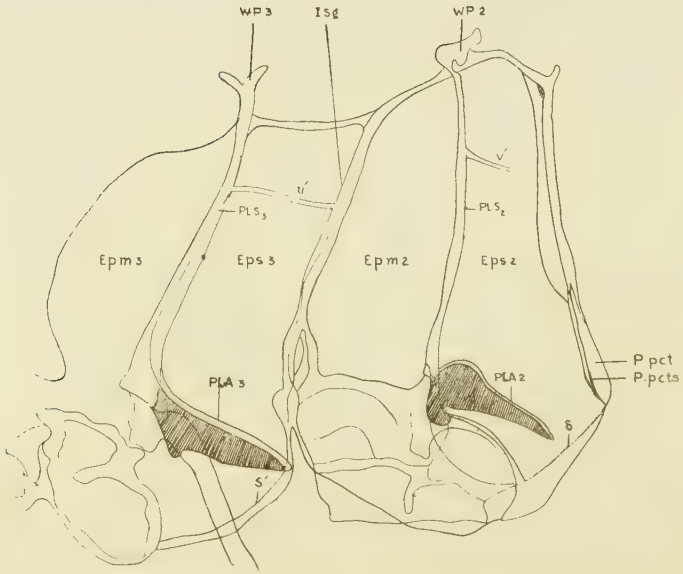
WP3
PN3
PL3
PL2
u'
v'
Eps 2
Epm 2
Eps 3
Epm 3
Iss
2 spr
Mer
P.p ct
cx1
S'
cx3
S

Fig. 25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Isg
WP2
v'
u'
PLS3
PLS2
Epm 3
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Epm 2
Eps 2
P.pct
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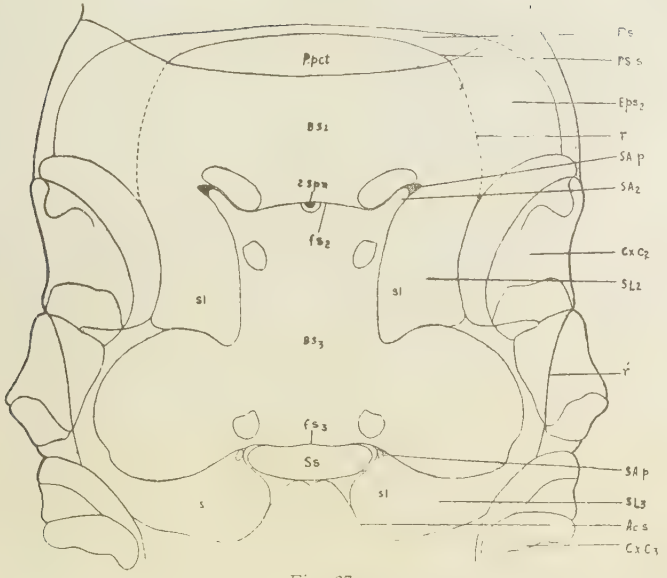
PLA 3
PLA 2
δ
S'

Fig. 26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Ppct
PS s
Eps2
BS1
r
SA p
z.spn
SA2
fs2
Cx C2
SI
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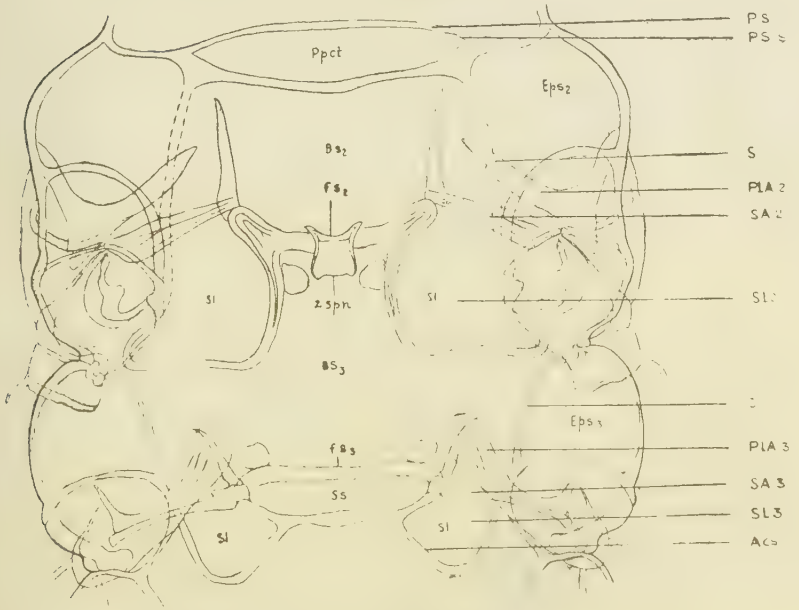
SL2
BS3
r'
fs3
Ss
SA p
SI
SL3
Ac s
Cx C3

Fig. 27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Ppct
Eps2
BS2
S
fs2
PLA 2
SA 2
SI
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SI
SL2
BS3
r
Eps3
PLA 3
fs3
SA 3
Ss
SL3
SI
SI
Ac s

Fig. 28

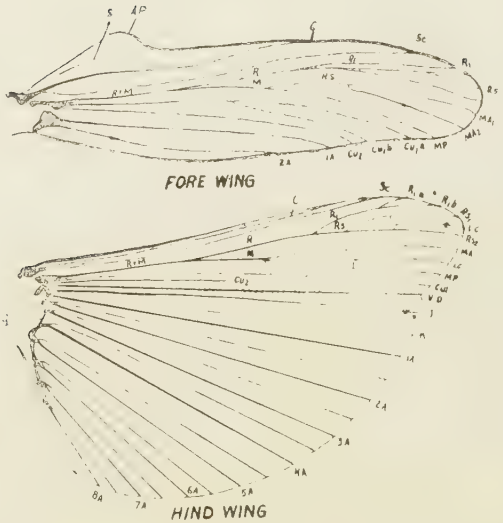
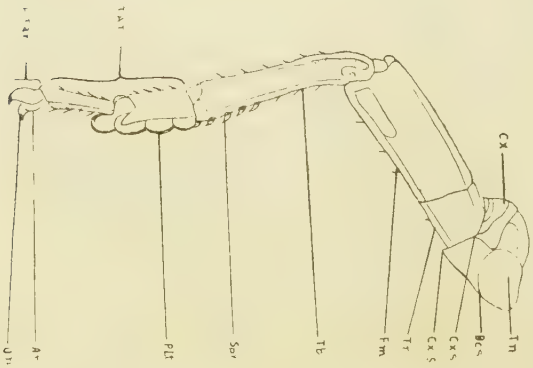


Fig. 29

Fig. 30



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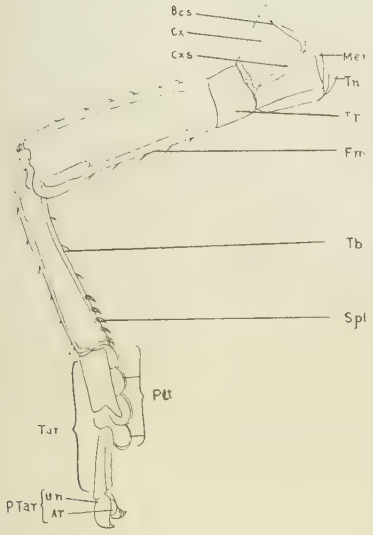
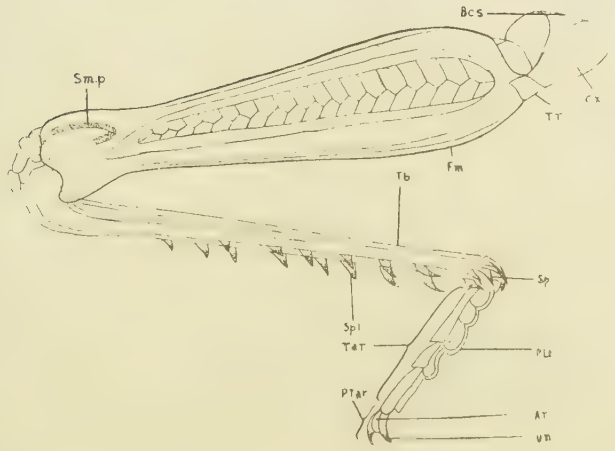


Fig. 32

Fig. 34

Fig. 35



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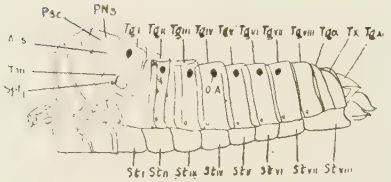
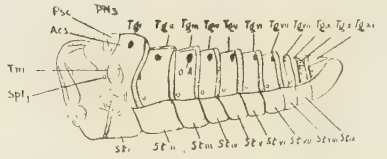

Psc
PNs
Tg I
Tg II
Tg III
Tg IV
Tg V
Tg VI
Tg VII
Tg VIII
Tg IX
Tx
Tg XI
A s
Tm I
Spl I
St I
St II
St III
St IV
St V
St VI
St VII
St VIII

Fig. 36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Tg XI
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St II
St III
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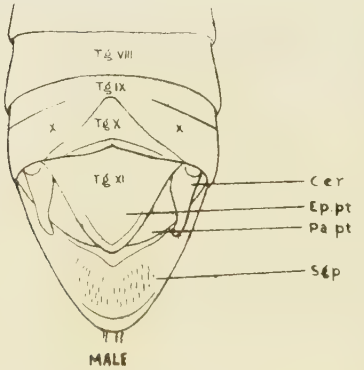
St V
St VI
St VII
St VIII
St IX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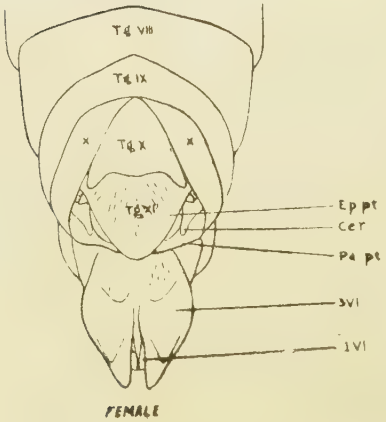
Tg IX
Tg X
X
X
Tg XI
Cer
Ep pt
Pa pt
Sep
MALE

Fig. 37


Tg VIII
Tg IX
Tg X
X
X
Tg XI
Ep pt
Cer
Pa pt
3VI
1VI
FEMALE

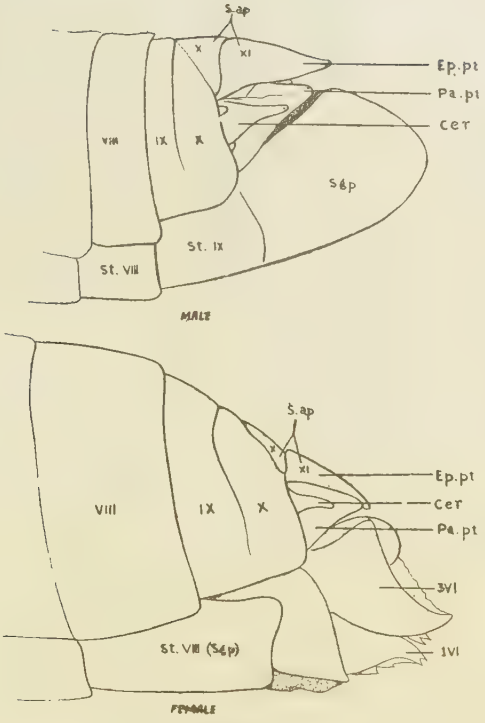
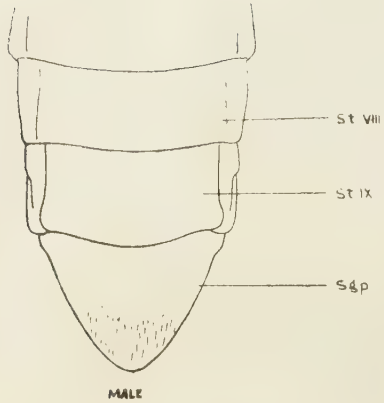

S.ap
X
XI
Ep.pt
Pa.pt
Cer
VIII
IX
X
S&p
St. IX
St. VIII
MALE
S.ap
X
XI
Ep.pt
Cer
Pa.pt
VIII
IX
X
3VI
1VI
St. VIII (S&p)
FEMALE

Fig. 38


St VIII
St IX
S&p
MALE

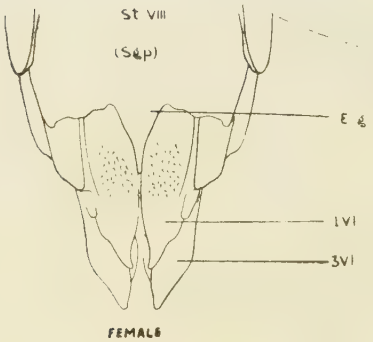

St VIII
(S&p)
E &
1VI
3VI
FEMALE

Fig. 39

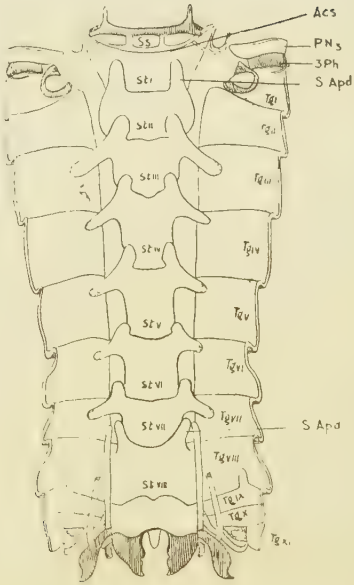

Acs
PN3
3Ph
S Apd
S Apd

Fig. 40

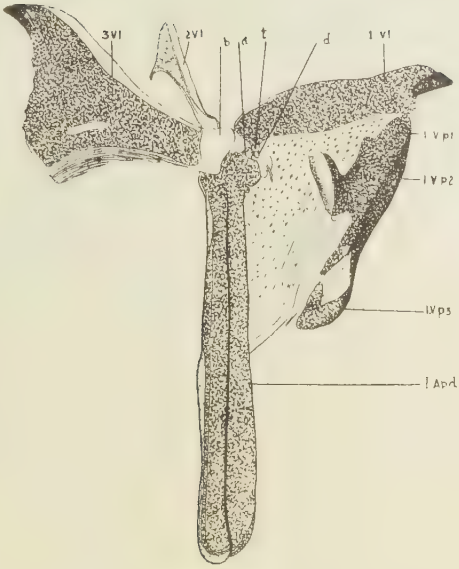

3VI
2VI
b
a
t
d
1 VI
1 VPt
1 VP2
IVP3
! Apd

Fig. 41

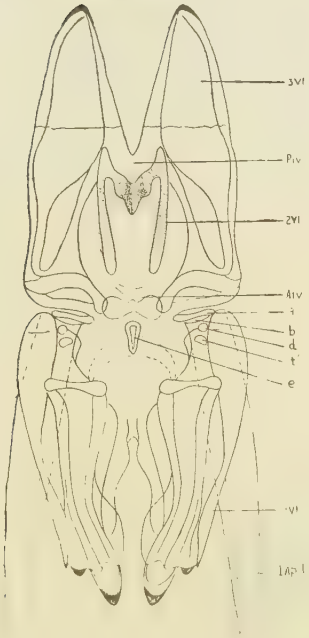

3VI
PIV
2VI
AIV
i
b
d
t
e
VI
1AP1

Fig. 42

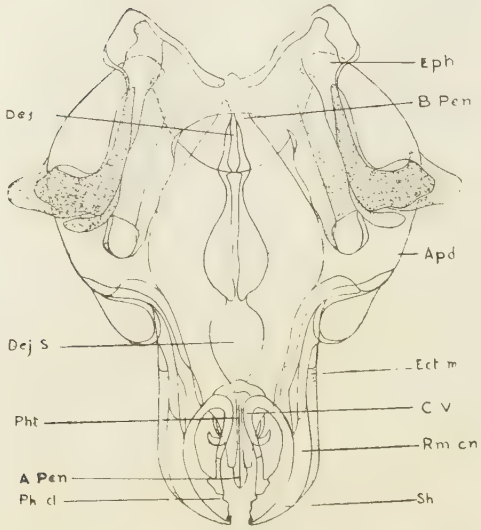


Fig. 43

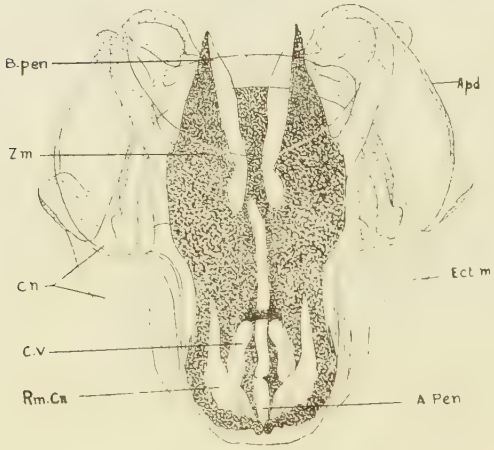


Fig. 44

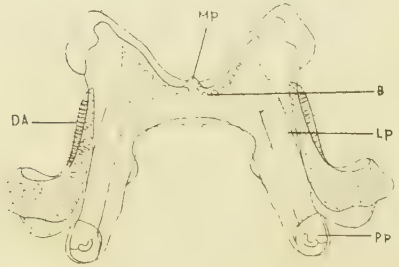


Fig. 45

Biology and Pathogenicity of *Rosellinia necatrix* (Hart.) Berl.

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Pakistan Forest Research Institute, Abbottabad.

Introduction 200
Relationship of *Dematophora* with *Rosellinia* 204
Rosellinia necatrix root rot... 205
1. Distribution 206
2. Host range 207
3 Morphology 211
(a) Mycelium 211
(b) Rhizomorphs 211
(c) Sclerotia 212
(d) Chlamydospores 212
(e) Coremia 212
(f) Pycnidia 213
(g) Perithecia 213
4. Pathology 214
(a) Symptoms 214
(b) Pathological anatomy 215
(c) Pathogenicity tests 216
(d) Resistance of species 222
(e) Other susceptibility trials with *Citrus* root stocks... 222
(f) Time required to kill the plants 223
(g) Mode and rate of spread of disease 223
(h) Conditions favouring the spread of disease 225
5. Control 227
Acknowledgements 234
Summary 234
References 235

INTRODUCTION

The genus *Rosellinia* was named by De Notaris in 1880 after Rosellini who was a doctor of medicine and naturalist in Pisa. The genus has about three hundred named species but Ainsworth & Bisby (1945) recognize only one hundred. Several species produce well defined root rot diseases and in exceptional cases give rise to cankers above ground. The genus is world wide in distribution, occurring both in tropical and temperate regions. The fructifications of most species are found on dead wood and bark and they are in the main assumed to be saprophytes. Since the perithecia of species known to be parasitic are also found on dead wood, no idea of the mode of existence of the fungus can be obtained from the perithecia alone.

The mycelium when young is white and profuse, and shows great tendency to form mycelial cords and a matty felt-like growth. It penetrates all underground parts of the plant and the activity is confined mainly to bark and on the surface of wood.

The fungus grows into the root system, plugs the xylem vessels and prevents the functioning of roots and rootlets and finally starves the plant.

The fruiting structures of *Rosellinia* do not develop until late in the season. The conidial stage appears late in the summer or early autumn. The perithecial stage develops very late in autumn or early winter. This stage in many species may take two or more years to develop and appears when the host tissue is in a very late stage of decomposition.

There are about a dozen species of *Rosellinia* which are worth mentioning so far as pathogenicity is concerned. They can be classified into four ecological types : (a) Temperate hygrophytes:- *R. necatrix*, *R. quercina* (b) Temperate xerophytes:-*R.* (?) *glomerata* (c) Tropical hygrophytes:-*R. bunodes*, *R. pepo*, *R. arcuata* (d) Tropical xerophytes:-*R. paraguayensis*.

It seems necessary to consider them briefly in order to bring out the varying conditions under which they develop and cause considerable damage.

Rosellinia aquila (Fr.) De Not. has been reported by Prilleux (1897) as the cause of a serious root rot of mulberry. In Scotland it has been seen to kill spruce seedlings (Wilson 1922). Boischot (1938) has observed this fungus in association with *R. necatrix* (Hart.) Berl. causing a serious

root rot of jasmine in France on argillaceous soils which maintain a high water content in winter. Morstat (1937) and Bordales (1929) have reported this species on coffee. Massee (1903, 1910) has stated that various other kinds of trees are slso attacked by this fungus. Lately Ahmad (1956) has reported this species from Pakistan on dead branches of *Dalbergia sissoo*, *Zizyphus jujuba* and *Ficus palmata*.

Berlese (1892) is opposed to the idea that *R. aquila* is a saprophyte while *D. necatrix* only is parasitic. Both of these species, he thinks, can live on dead branches and can become parasitic under suitable conditions According to Ramsey (1914) this species attacks many kinds of trees but is probably best known for its activity on mulberry roots. In California (U. S. A.) the fungus is a common saprophyte and could be mistaken for the parasitic species *R. necatrix*.

Rosellinia arcuata Petch was first studied by Petch (1910b) in Ceylon attacking tea bushes. This fungus was originally described under the name of *R. bothrina* by Berkeley and Broome. This species also attacks *Cinnamomum camphora*, *Crotolaria usarmoensis*, *Erythrina* sp., *Hevea*, *Indigofera endacophylla*, *I. dosua*, *Grevillea robusta*, *Leucaenia glauca*, *Panax fruticosum*, *Strobilanthus*, *Symplocos robusta*, *Tephrosia candida*, *T. vogelli*, and *Thea*. (Steinmann 1927, Gadd 1928, 1939, Vollema 1938, Petch 1910a, 1910b). The most remarkable feature of this species is its rapid spread in the upper two to three inches of soil. It has been observed to travel three to four yards in a few weeks. It prefers soil which contains a large percentage of leaves. It presumably takes its start from the dead leaves and stumps and spreads attacking the roots of living plants. Gadd (1928, 1939) in a number of short notes has emphasised the importance of stumps and leaf mould in the spread of this fungus. Tunstall (1923) has reported this fungus to be particularly susceptible to lime. Suba Rao (1941) found it on tea and has suggested excision of diseased roots and use of one percent Burgundy mixture.

Rosellinia bunodes B. & Br. was first described by Berkeley and Broome from Ceylon. Since then it has been reported from South India, West Indies, Sumatra, Java, Columbia, and Peru. It is active under humid conditions and causes serious losses in arrowroot, avacado, banana, cacao, cassava, coffee, Sea Island cotton, ginger, seedlings of grapefruit, pigeon pea, rubber, *Sterculia carbea*, tea and yams. Fawcett (1915) has reported it on *Acalypha mosaica*, *Gratophylium pictum*, *Miconia*, *Palicouria*, *Panax*

plumatum, Rose apple and *Tradescantia*. Butler & Bisby (1931) listed it on the bases of trunks of coffee, *Grevillea robusta*, *Holigarna longifolia*, *Litsea angustifolia*, *L. wightiana*, *Piper nigrum*, and *Schleichera trijuga*. South (1922) has observed this fungus on a number of hosts such as cacao, coffee, *Grevillea robusta*, lime and forest trees, killing the trees very rapidly. Briant (1934) described an interesting disease on arrowroot in St. Vincent and the same disease has also been recorded by Nowell as burning disease of arrowroot. Nowell (1915, 1916c, 1916d) and Fawcett (1915) have described in detail the black root rot of limes. According to them the best lime trees are attacked. The fungus advances ten to twelve feet in one year in soil (Fawcett). The disease due to this fungus has also been a subject of study by a number of workers such as Abbott (1929), Bally (1930a, 1930b.), Chardon (1927), Teodoro & Gomez (1926), Kahs (1938), Keuchenius (1939), Matz (1920), Muller (1939), Smith (1929), Tucker (1929), and Van Heusden (1937).

Rosellinia caryae Bonar. This species was found by Lee Bonar in 1922 on young twigs and trunks of *Carya ovata* producing cankers on vigorously growing shoots. The cankers run longitudinally and do not girdle except on very young twigs. The presence of numerous cankers gives the tree a gnarled and distorted look. New shoots arise at the base of dead ones and infected in turn. The imperfect stage is *Dothichiza caryae* Bonar.

Rosellinia clavariae (Tul.) although not a pathogene of fruit trees and other plants, is interesting on account of its parasitism on other fungi such as *Clavaria cinerea* producing at the bases of the fruit bodies of those fungi a blackened discoloration. The conidial stage has been identified as *Helminthosporium clavariorum* Desm.

Rosellinia echinata Massee, has been reported as a very destructive parasite of *Ficus dubia* and many dicotyledonous shrubs and herbs including rattans, dracaenas, and even some diffenbachias, (Massee, 1901, 1903).

Rosellinia herpotrichioides Hepting & Davidson. This fungus attacks the branches and leaves of hemlocks (*Pseudotsuga canadensis*) causing yellowing of leaves on the lower branches. It may cause 80% defoliation among the trees under fifteen feet in height.

Rosellinia ligniaria Nitschke, was observed by Carruthers in 1897 attacking and eventually killing living ash and Ostrya trees (Massee 1910).

Rosellinia pepo Pat. originally described by Patouillard in 1908 on the bark of *Hymenaea courbaril* from Guadelope, has since then been recorded from West Indies, India, Ceylon and other tropical countries. The fungus attacks bananas, breadfruit, bitter orange, cacao, cassava, *Cassia fistula*, dasheens, horse bean, *Inga* sp., limes, mango, orange, and pigeon pea. Sugarcane is fairly resistant and cocoanut is immune. The general importance of this fungus lies in its attack on cacao, coffee and limes. It is distinguished from other species by the fans or stars of white mycelium formed in the region of the cambium between the bark and the wood of the roots. Strands of mycelium also penetrate the wood in radial lines along the medullary rays. The fungus has been studied by Nowell (1916a, 1916c, 1916d, 1919, 1920, & 1923), Fawcett (1936), Briton-Jones (1928), Kadan (1932), Botero (1937), Casella (1930), Dwyer (1937), Jong (1942), Walters (1935) and Waterston (1941).

Rosellinia quercina Hart. occurs in seed beds as a serious parasite of young oak seedlings affecting the roots and lower parts of the stem. The disease has been known to exist in Germany since the middle of the eighteenth century and was first recognized by Hartig (1880, 1894 as *Rhizoctonia quercina*, but later studies led him to change the name to *Rosellinia quercina*. In recent years Waldie (1930) has given a good account of the disease from England. The fungus kills a number of species of oaks viz., sessile oak (*Q. robur sessiliflora*), pedunculate oak (*Q. robur pedunculata*), Turkey oak (*Q. cerris*). Waldie's attempts to infect spruce and coniferous seedlings failed. Oak seedlings one to three years old, die in patches with the approach of warmer conditions and the disease progresses gradually till the whole bed is ruined. While discussing the symptoms Waldie pointed out that *Rhizoctonia*, which has mycelium very similar to *Rosellinia*, can be distinguished by the presence of clamp connections not seen in the latter.

R. corticium has also been reported from Pakistan from Murree Hills (Ahmad, 1956). *Rosellinia mangiferae* Syd. (in Syd. et Bulter, Ann Mycol. IX, 1919, P. 405) has been reported on the bark of *Mangifrea indica* from Chittagong.

Rosellinia necatrix. Of all the species *Rosellinia necatrix* is most destructive in the temperate climates. The relationship of imperfect stage has been a source of much controversy as will be clear from the following account.

RELATIONSHIP OF DEMATOPHORA WITH ROSELLINIA.

Robert Hartig (1883) on observing the conidiophores of *Rhizomorpha necatrix* from the sclerotia on rotten roots came to the conclusion that these conidial structures could not be allocated to any known form at that time. These were in his opinion very close to *Rhinotrichum* but on the basis of the coremium, zigzag terminal hyphae forming fascicles, non-septate ovoid conidia and simple paraphyses, Hartig assigned these to a new genus *Dematophora*. He left the question of systematic position of the fungus to be decided when the ascocarp was found. He, however, on the basis of his observations on *R. quercina*, forecast the relationship of the imperfect stage to the genus *Rosellinia*.

Viala (1891) on the basis of polymorphism, organization and development of *R. necatrix*, came to the conclusion that the *Dematophora* species should be placed in a new family *Dematophoraceae* among the ascomycetes and classed it with Tuberaceae not observing the distinct ostiole. Viala did not think it advisable to change the name, and adopted *Dematophora* as the name for the perfect form too.

Berlese (1892) in two papers on *Rosellinia aquila* established the relationship between *Dematophora* and *Rosellinia*. Berlese's views were in marked contrast to Viala's. In Berlese's opinion the supposed absence of an ostiole, the basis on which Viala tried to separate it from *Rosellinia*, was not important enough to remove the fungus from the Pyrenomycetes when all other characters were conducive to its inclusion in that group. He still believed that a proper ostiole was absent, and stated that in Pyrenomycetes there were species which were perfectly globose, lacking ostiole, rugose, coriaceous,and aggregated. In *Rosellinias* also there were some species with ostioles inconspicuous or lacking. Therefore, the absence of an ostiole was not enough to exclude the perfect stage of *Dematophora* from the genus *Rosellinia*. He further considered *Rosellinia* to be closely related to the genus *Hypoxylon*.

Prilleux (1902, 1904) supporting Berlese's views on the inclusion of the perfect stage of *Dematophora* in the Pyrenomycetes, wrote that although the lack of ostiole in perithecia appeared to Viala to justify its inclusion in the *Tuberaceae* and the creation of a new family Dematophoraceae, yet *Dematophora* presents in all its characters such a great analogy with *R. aquila* and *R. quercina* that it scarcely appears possible to place it in another family. Besides, he added, the existence of an

ostiole might have been misunderstood because Viala did not have, at his disposal, a large number of perithecia. In conformity with Berlese, he surmised that the name *Dematophora necatrix* should be changed to *R. necatrix*.

Ferraris (1909) summarized the views of Berlese and Prilleux and referred it (*Dematophora*) to the genus *Rosellinia* in the *Sphaeriaceae*. The conidial stage was regarded by him to belong to *Graphium* in the family *Stilbaceae*.

The conidial stage of *R. necatrix* has not been subjected to reshuffling a number of times. It was changed to *Graphium necator* (Hart.) Trave. at one time and in recent years Goidanich (1935) has created a new genus *Pleurographium* with *D. necatrix* as the type species. Mason (1937) has reviewed the situation and has poined out that *Dematophora* typifies a group of species which have at various times been included in the genus *Graphium* but differ from it (a) in having dry conidia which show no polymorphism and (b) in not having shiny heads of conidia. He has further added that because *Dematophora* and *Pleurographium* have the same type species they must be considered as synonyms. Thus it is still *D. necatrix* in spite of being tossed about.

Hansen, Thomas & Thomas (1937) gave convincing proof of the connection of *Dematophora* and *Rosellinia* by germinating the ascospores and obtaining the *Dematophora* stage and proving its pathogenicity. The last step of obtaining perithecia again from the ascospore cultures, however, still remained. The ascospores were obtained from perithecia which had developed on the naturally infected material incubated for two years in the laboratory.

Several attempts were made during the present investigation to obtain perithecia in cultures but no success was obtained. Further details of these experiments are given later on in this paper and elsewhere (Khan, 1956).

ROSELLINIA NECATRIX ROOT ROT

The disease caused by *R. necatrix* (Hart.) Berl. is very destructive in nature and is known under a variety of names: White Root-Rot or *Dematophora* Root-Rot; *Weinstockfaule*; *Blanc*, *Blanc des racines*, *Grappes* (Aube), *Mortaouses et Terres betes* (medoc), *Bianco*, *Malbianco*, *Marciume* and *Marciume radicale* and *Malnero*.

Earliest mention of this disease is by Schnetzler (1877) from Switzerland who also referred to its occurrence in France and Germany on grapes. Frank (1880, 1896) proved the pathogenicity of the disease by inoculation experiments. Le Monnier (1883) considered the causative fungus to be *Roesleria hypogaea*. Prilleux (1881, 1897, 1902, 1904) referred to the spread of disease over 1,500 hectares: he distinguished it from root rot due to *Armillaria mellea* but mistook it for *Roesleria hypogaea*.

Thumen (1883) reported this dissase from Austria in 1879. Hartig (1880, 1883, 1894) published his fine monograph on *Dematophora necatrix*. He summarised all the previous information and made an exhaustive study of the fungus responsible for the disease. His studies resulted in the creation of a new genus, *Dematophora* and a new species *D. necatrix*.

Wight (1889) and Cunningham (1925) have reported this from New Zealand. The latter considered peach as somewhat resistant.

Viala (1891) published a big monograph on Pourridie. These investigations were conducted independently and simultaneously in France when Hartig was busy in Germany. Hartig's work appeared earlier and Viala drew copiously upon the work of the former.

Salmon (1913) and Nattrass (1927) reported this disease from England. The latter referred to its occurrence in that country since 1900.

A definite step towards resolving long standing question of relation of *Dematophora* with *Rosellinia*, was accomplished by Hansen, Thomas & Thomas in 1937.

I. DISTRIBUTION

The disease is world wide in distribution, but has not been reported from central tropics.

Although earliest reference to the occurrence of disease in United States of America dates back to 1837 yet the proven records till lately are few. Thomas, Hansen & Thomas (1934) recognized the disease in California in 1929. Disease has been noticed in California in orchards set on land cleared of Redwood and other native growth. Reports (*) indicate that the disease has been there for the last twenty years and is found in fourteen counties of California. It is very doubtful that even to-day, the disease occurs anywhere in U.S.A. except California.

Foot Note:— (*) Information based on unpublished notes of Dr. Harold E. Thomas (HET) in the files of Division of Plant Pathology, Berkeley.

2. HOST RANGE

Hartig (1883), Millardet (1879), Viala (1891), Wight (1889), Blunno (1911), Pethybridge (1926), Beaumont & Hodson (1929), Staniland & Beaumont (1937), each have listed a number of plants in their accounts. Palm (1933) recorded it on algae. The species affected by this fungus are given in table I. In all 170 species and varieties of plants are susceptible to it. The range of pathogenicity covers 63 genera, 30 families of higher plants and three algae.

Table I.

Showing the Host Range of Rosellinia necatrix.

Name of host	Common Name	Place	Reported by	S or R *
Abies pectinata (Coniferae)	Fir	Europe	Hartig	S
Acacia sp. (Leguminoseae)	Acacia	Italy		S
Acer sp. (Sapindaceae)	aple	Europe	Hartig	S
Annona sp. (Annonaceae)	Custradapple	Sicily	Montemartini	S
Berberis sp. (Berberidaceae)	Barberry	Berkeley U.S.A.	HET	S
Beta vulgaris (Chenopodiaceae)	Beet	Europe	Hartig	S
Beta vulgaris var. cicla (Chenopodiaceae)	Swiss Chard	Calif U.S.A.		S
Brassica oleracea (Cruciferae)	Cabbage	Australia		S
Ceanothus megacarpus (n) (Rhamnaceae)		Berkeley	HET	S
Citrus sp. (Rutaceae)	May not be necatrix	U.S.A.		S
Cladophora	Alga		Palm	S
Coffea sp. (Rubiaceae)	Coffee	Brazil	Averna-Sacca	S
Corylus colurna (Betulaceae)		Germany	Hartig	S
Cotoneaster (Rosaceae)				
C. buxifolia ,,				
C. francheti ,,				
C. frigida ,,				
C. lactea ,,		Box test		
C. pannosa ,,		at		
C. salicifolia ,,		Berkeley U.S.A.	HET all	S
Cyclamen (Primulaceae)		England		S
Cydonia oblonga (Rosaceae)	Quince	Field plot U.S.A.	HET	S
Echium (Boraginaceae)	Vipers-buglose	San Mateo ,, county ,,	HET	S

* R—Resistent

* S—Susceptible

Ficus carica (Moraceae)	Fig (black-mission)	Field ,, plot ,,	HET	S
Fragaria sp. (Rosaceae)	Strawberry	Box test	HET	S
Fagus sylvetica (Fagaceae)	Beech	France Germany	Viala Hartig	S
Genista sp. (Leguminoseae)	Broom	Italy	Beaumont	S
	Gosseberry	England		
Hydrodiction sp.	Alga		Palm	S
Iris sp. (Iridaceae)	Iris	England		S
Ixia sp. ,,	Ixia	,,	Beaumont	S
Jasminum officinale (Oleaceae)	Jasmine	France England	,,	S
uglans (Juglandaceae)	Butternut	Boxt U.S.A.		
cinerea ,,	N. Calif. black	field ,,		
hindsii (n) ,,	Eastern black	plot	HET	S
nigra ,,	3 blood-royal			
Rumex sp. (Polygonaceae)	Docks	Australia New-Zealand	Whight	S
Larix europea (Coniferae)	Larch	Europe	Hartig	S
Ligustrum sp. (Oleaceae)	Privet	Calif U.S.A.	HET	S
Medicago sativa (Leguminoseae)	Alfalfa	Banning, Cal.	Harris	S
Montbretis (liliaceae)	ontbretia	England ,,	Beaumont	S
Morus sp. (Moraceae)	ulberry	France	Boischot	S
Narcissus sp. (Amyrillidaceae)	Narcissus	England	Beaumont	S
Olea europea (Oleaceae)	Olive	Italy	Petri	S
Osmanthus acquifolium (Oleaceae)		Napa		S
Osmaronia cerasiformis (n) (Rosaceae)	Osoberry	Boxt test U.S.A.		S
Paeonia (albiflora ?) (Ranunculaceae)	Peony	San Leandro ,,	Hansen	S
Phaseolus sp. (Leguminoseae)	French bean	England		S
Photinia arbutifolia (Rosaceae)	Toyon	Box test U.S.A.		S
Picea excelsa (Coniferae)	Spruce	Europe	Hartig	S
Pinus sylvestris (Coniferae)	Pine	Europe	Hartig	S
Pistacia vera (Anacaridaceae)	Pistacio	Uzbekisten	Zaprometoff	S
Populus nigra (Salicaceae)	Lombardy poplar	Niles		S
Potentilla glandulosa (n) (Rosaceae)		Box test U.S.A.		S
Prunus (Rosaceae)				
armenica ,,	Apricot	Field polt ,,		S
avium ,,	Cherry	,, ,, ,,		S
besseyi ,,	Sand cherry	Box test ,,		S
capuli ,,		,, ,, ,,		S
cerasifera ,,	yrobalan	Field Plot ,,		R
cerasus ,,	Sour cherry	Field plot ,,		S
communis ,,	Almond	Field polt ,,		S
ilicifolia (n) ,,	Catalina cherry	Box test ,,		S

persica	Peach	Field plot ,,		S
Pyracantha koidzumii (Rosaceae)	Firethorn	Box test		S
Pyrus malus (,,)	Apple	Kent		S
Bramley's seedling	,,	England	Salmon	S
Beauty of bath	,,	,,	,,	S
Lord Derby	,,	,,	,,	S
baccata	Crab			S
Pyrus				S
Malus				S
Seedlings of Golden				S
Delicious and	Apples	England	Pethybridge	S
cIntosh				S
Rochii				
also East alling clones and Cox's orange				
Pyrus (Rosaceae)	Pear			S
balansae ,,				
betulaefolia ,,			all	S
bretscheideri		Field plot ,,		S
calleryana		,, U.S.A.		
communis		,,		
cordata		,,		
cotinifolia		,,		
glabra		,,		
heterophylla		,,		
ovoidea		,,		
persica		,,		
phaeocarpa		,,		
serotina		,,		
serulata		,,		
ussuriensis		Field plot U.S.A		
var. Bonne Louise	Pear	France	Viala	S
,, Beurre d' Amanlis	,,	,,	,, less	S
,, Beurre de Paris	,,	,,	,, ,,	S
,, Beurre Clergeau	,,	,,	,, ,,	S
,, Beurre Gifford	,,	,,	,, ,,	S
,, D'Avranches	,,	,,	,, ,,	S
,, Duchesse	,,	,,	,, ,,	S
,, Williams	,,	,,	,, ,,	S
Quercus sp. (Fagaceae) White	Oak White oak	Europe	Hartig	S
green	Green oak	France	Viala	S
Rhamnus Californica (n) (Rhamnaceae)	Coffee-berry	Berkeley U.S.A.	HBT	S S
R. alternatus ,,		Germany	Hartig	S

Rhododendron (Rosaceae)	Rhododendron	Italy	Petri	S
Rosa sp.	Rose	,,		S
Ribes sp. ,,	Red current	Alameda county U.S.A.	HET	S
Ribes sp. (Saxifragaceae)	Gooseberry	England	Salmon	S
Rubus proceras	Himalaya black berry	Field plot U.S.A.	HET	R
ursinus ?	Boysenberry	,, ,,	,,	S
ursinus ?	Loganberry	,, ,,	,,	S
ursinus ?	Youngberry	,, ,,	,,	R
vitifolius (n)	Wild black berry	,, ,,	,,	S
Salix sp. (Salicaceae)	Willow	Uzbekistan	Zaprometoff	S
Solanum tuberosum (Solanaceae)	Potato	England	Salmon	S
Sorbus aucuparia (Rosaceae)	Rowan tree	Boxt test U.S.A.		S
Tulipa sp. (Liliaceae)	Tulip	England		S
Ulmus (Ulmaceae)	Elm	,,	Pethybridge	S
Vaucheria sp.	Alga		Palm	S
Viburnum sp. (Caprifoliaceae)		San Mateo County	Harris	S
Viola sp. (Violaceae)		England		S
Vitis sp. (Vitaceae)	Grape	Field plot		S R
Vitis rupestris (Vitaceae)	,,	France U.S.A.	Viala	S
Vitis rotundifolia (Vitaceae)		France & Australia	Blunno	R
Vitis cinerea ,,		France	Viala	R
Vitis vinifera ,,		,,	,,	S
Var. Grenache		,,	,,	S
,, Teinturier du Cher		,,	,,	S
,, Carignane		,,	,,	R
,, Pinots		,,	,,	R
,, Riesling		Germany	Sorauer	S R
,, Rupestris DuLot		Australia	Blunno	S
Rupestris metallica		,,	,,	S
Riparia Grand Glabre		,,	,,	S
Riparia gloiredde Montpellier		,,	,,	S
Rupestris Martin		,,	,,	S
Mourvedre X rupestris Riparia-rupestris-1202		,,	,,	S
Cordifolia X Riparia-rupestris-1068		,,	,,	S
Aramon X Rupestris-Ganzin No. 1		Australia	Blunno	S
Riparia X Rupestris-Coudrec		,,	,,	S
Riparia X Rupestris-Millardet		,,	,,	S

Tokay on Mourvedre X Rupestris 1202		,,	,,	S
Rulander		Germany	Sorauer	S R
White burgunder		,,	,,	S R
Ortlieber		,,	,,	S R
Traminar		,,	,,	S R
Mleskateller		,,	,,	S R
Elbling		,,	,,	S R
Blue silvaner		,,	,,	S
Gutedel		,,	,,	S
Solonis X Riparia 1616		,,	,,	R
Jurancon		France	Hillardet	S
Malbec		,,	,,	S
Zantedeschia aethiopica (Araceae)	Arum	England	Beaumont Pethybridge	S
Zizyphus jujuba (Rhamnaceae)	Jujube	France	Viala	S

3. MORPHOLOGY

(*a*) MYCELIUM : The hyphae are of two types; *thin* 2-5 μ hyaline becoming darker on drying; brown *large* hyphae measure 4-8 μ in diameter. The pear shaped swellings are seldom seen in young, but common on isolated and old hyphae (Fig. 1). In moist chamber large fan shaped mycelial felts are formed (Fig. 4). 'H' connections are also seen.

In nature, the mycelium develops under bark, as vague fan-like, thin mycelial sheets. Just above these subcortical mycelial ribbons, hyphal strands grow outwards and form sclerotia.

(*b*) RHIZOMORPHS : Rhizomorphs have been recorded for this fungus. The conception on rhizomorphs however has varied with different workers on this fungus. Hartig (1880, 1883, 1894) regarded the mycelial ribbons spreading on the surface of wood under the bark as 'Rhizomorphs' which are equivalent to *Rhizomorpha subscorticalis* of Viala (1891) and later workers. In modern concept of the term, it should be be applied to a well organised cordlike structure, well differentiated into cortex and medulla and a growing point, as we find in *A. mellea*. During the present investigation, however, the writer has never seen anyr hizomorphic structures comparable to those of *A. mellea*.

Under field conditions only loose *mycelial strands* of mouse gray or brown colour are seen. In warm humid conditions white diffuse fans with prominent ribs representing centre of the strand are produced which darken with age.

Another structure which could be compared to Hartig's '*Other types of rhizomorphs*' described for *R. necatrix*, has been observed by the writer in the following cultural studies.

Bits of infected material were 'stabbed' into prune dextrose agar and after about three weeks, dark, thin, fingerlike processes were produced inside the agar (Fig. 5). These short cylindrical branches attained a length of 0.5 to 1.8 cm. and never grew any further. The tips were white but the older portions were black. Under the microscope they appeared to be blackish brown with many fine hyaline hyphae in adjacent agar. In a longitudinal section the structure resembles very much the true rhizomorphs of *A. mellea* but are much shorter and darker than comparable rhizomorphs of *A. mellea* on the same medium. The brown hyphae showed pear shaped swellings here and there. Typical cultures of *D. necatrix* were obtained from bits of these on potato dextrose. These cultures were reinoculated into sterilized quince twigs and when these were covered over with a black sclerotial crust they were again stabbed into prune and potato dextrose agar tubes. In prune agar the 'rhizomorphic' processes were again obtained in some cultures but never in potato dextrose.

These peculiar 'rhizomorphs' were also produced on twigs slightly or half immersed in water. These structures are apparently produced only in very wet, water logged or other abnormal conditions of aeration and nutrition and do not have any significance in usual life cycle of the fungus.

(*c*) SCLEROTIA : Hartig described pseudoparenchymatous protuberances on the surface of invaded stems. They are formed of loose tissue, and are small, tough, irregularly spherical nodules which coalesce, 0.5 mm in diameter. But in the experience of the writer dark sheet-like patches or coalesced masses are more common.

(*d*) CHLAMYDOSPORES : The chlamydospores have been reported but are not believed to be of any importance in the life cycle of the fungus, if indeed a part of it. They were never observed by the writer.

(*e*) COREMIA : The conidiophores arise on sclerotia or old mycelium. They are rigid, erect, thick at the base, thinner at the top, 1.5 mm in length,

intermixed with light coloured setae (Figs. 2,3). They arise singly or in groups of 1-12 usually near the soil level. The ultimate conidium bearing branches are geniculate and measure 10.30 μ in length (fig. 2 b). Each branch bears 15-20 spores. Conidial buds are developed and pushed aside alternately. Conidia are unicellular and ovoid, 2-3 μ long and 1.5 μ broad, hyaline with homogeneous protoplasm and without obvious vacuoles. It is doubtful if they germinate.

(*f*) PYCNIDIA : Viala (1891) reported pycnidia but these probably belonged to some other fungus. No pycnidia were ever observed by the writer.

(*g*) PERITHECIA : Hartig (1880, 1883, 1894) did not find perithecia but on the basis of his work on *Rosellinia quercina*, he forecast correctly the relationship of *Dematophora* with *R. necatrix*. Later works of Berlese (1892), Prilleux (1881, 1897, 1902) and Hansen, Thomas & Thomas (1938) have established the connection of *Dematophora* with the perfect stage of *Rosellinia*.

Perithecia are rarely found in nature. They appear intermixed with conidiophores on host tissues in advanced stages of decay. The perithecia are 1.5 mm in diameter or a little more, globular, brownish gray, depressed a little at the apex with a projecting papilla which has brownish black ring around it (Fig. 2). The peridium is thick, of two layers, the external layer composed of thick walled irregularly fused hyphae, and inner layer of thin walled, septate, brown, intertwining hyphae having pear shaped swellings. Inside the peridium, is another relatively thicker net work of colourless hyphae, inner most layer of which produces the hymenium. The thin whitish inner layer of peridium on drying, becomes thin, yellowish and papery while the outer wall remains black, hard and carbonous.

There is a definite round pore at the apex of papilla (Fig 3, 4). The pore is not discernable in old perithecia that have ceased to discharge spores because the opening becomes filled with dried gelatinous material in which the spores are exuded.

The asci are filiform, elongated, cylindrical, narrowed in the lower portion into a pedicel which has the same diameter as the paraphyses. The asci are 365 to 380 μ long and 8.5 to 9 μ broad. There are eight obliquely disposed spores in a row in each ascus (Fig. 2 e). The spores are not filled up to the top portion of the ascus which is occupied by a

thickened plug-like tip, coloured blue by iodine. The spores are spindle shaped, a little bulged on one side and pointed at both ends and measure 31 to 47 x 5 to 7 μ. In the middle of each spore there is a slit or suture running parallel to the long axis about one-third its length (Fig 3, c, d) through which it germinates.

4. PATHOLOGY

(*a*) SYMPTOMS : Millardet (1879), Hartig (1880, 1883, 1894), Viala (1891), Starnes (1895), Frank (1880, 1896), Nattrass (1927), Moore (1839) and Saccardo (1911) have discussed the symptoms on various plants including grapevines, apple and narcissus etc. The observations of the writer in the greenhouse and field on the symptoms and signs of disease, indicate that symptoms can be classified under three general groups but all three types may not be seen on one and the same plant.

1. *Defoliation and slow death* : The plants show retarded growth, leaves fall off early and not infrequently new shoots are given off from healthy portions. The leaf fall may be severe and scanty foliage is left over (Figs. 6-8). New shoots also gradually decline and small leaves keep almost parallel to the shoot without spreading outwards. The plant declines in vigour and dies. By this time the fungus will be seen covering the entire root system. Under moist conditions, a day or two after watering, a white mycelial fan is seen coming out and spreading on the surface of the soil especially around the stem. On potted plants under greenhouse conditions the fungus passes down through the hole at the bottom of the pot and spreads on wooden boards. Such symptoms have been seen in pear, apple (Figs. 6-8), and walnut (Fig. 9). Frequently when earthball of dead plants is taken out, one finds mycelium spreading in the roots and earth, all around along the inner surface of pots (Fig. 9).

2. *Wilting* :- The plant at first shows signs of slight withering and drooping of tender foliage as if it needed water. The wilt is complete in a few days time. Large plants take longer time to die. Affected plant simply dries up in a short time with all leaves hanging on it (Fig. 10). These symptoms have been seen especially in young *Citrus* rootstocks, *Camelia*, *Cotoneaster*, *Myrobalan*, *Holodiscus*, Plum, *Rehoba* Palestine sour, Rough lemon, Quince, Paeony, Sour orange, Sugar pine and Walnut (Figs. 11-14). Under warm humid conditions the fungus may spread on soil surface around the stem. The symptoms in other cases may be diffuse and comprise of categories (1) and (2) mentioned above. As is

characteristic of various root rots, the older plants bear a heavy fruit crop before they die.

3. *Gradual stunting of new growth and killing of older plants* :- These symptoms are characteristic of Strawberries, Raspberries and Loganberries (Fig. 15). Raspberries and Logans keep on sending out new shoots as if activated by the fungus which insidiously maintains its slow progress and kills them one by one. In final stage whole plant becomes bushy and no vigorous canes are sent out, but green leaves still come out from thin shoots. The plants die a slow lingering death.

The disease may be distinguished from *Armillaria* and *Xylaria* by the absence of well defined rhizomorphs or stromata and the presence of profuse white cottony mycelium adjacent to affected roots, in moist air, in laboratory, or in soil cavities in the orchard (Fig. 16). Coremia are occasionally found near the ground line on trees killed by the disease. They are formed also in pure cultures of the fungus grown on steamed kernels of wheat and oats.

(*b*) PATHOLOGICAL ANATOMY. The fungus may at first spread on the surface and then penetrates through epidermis, cortex to medullary rays. It grows in inner bark and cambial zone. Masses of mycelium, the 'cellular sclerotia' of Hartig (1880, 1883, 1894) are seen in the parenchymatous tissue of the periderm. Mycelium advances more slowly and unequally in phloem, wood and medullary rays and may fill them completely. A brown plastic substance is deposited in the intercellular spaces. The protoplasmic contents of parenchymatous cells are changed to brown a little distance from the hyphae. Starch grains are dissolved slowly and are often seen entangled in the mycelial strands. After the decay of parenchyma, xylem and phloem fibres may be exposed. Hyphae dissolve the middle lamella rapidly and a large mass of separated cells is left behind. Lignified walls and wood fibres are decomposed and rendered partly gelatinous. In final stages druses are common. Black zone lines arise in the wood.

Frank (1880) Perotti (1940), Ferraris (1909), Hartig (1880, 1883, 1894), Viala (1891) and Garovaglio (1883) have also record somewhat similar observations.

The hyphae passing out of medullary rays to wood become fine and pass in all directions. They are often seen running longitudinally in the xylem vessels, density of mycelium in the different tissues, in decreasing

order is: medullary rays> cambium> and phloem) the bark> and wood. The portion of a hypha passing through the wall is much thinner than on either side of the wall (Fig. 1 a). This shows that tip excretes a cellulose dissolving enzyme and not the whole body of he hyphae.

Underneath the bark, hyphae become aggregated and form a pseudo-parenchymatous felt.

(*c*) PATHOGENICITY TESTS. Tests on the pathogenicity and host range of fungus were carried out during 1946-48 in California. During the course of these investigations diseased material was either collected or received from various places for examination. Isolations were made from representative samples and numbered. Thirty isolations were made from each specimen received or collected. Following isolates were used in inoculation experiments.

No. 1-cherry, Watsonville. No. 2-cherry, Watsonville No. 3-paeony, San Leandro. No. 4-Paeony, San Leandro. No. 5-walnut, Orange-county. No. 7-pear, Milpitas, No. 8-apple, Watsonville. No. 9-pear, San Juan. No. 10-apple, Monte Rio.

Inoculation tests were carried out with potted plants as well as with plants grown in large boxes 3 x 10 x 1 ft. filled with sandy loam. In the first box test, plants were allowed to become established before inoculation. During earlier trials the plants were inoculated by laying bare a root and placing 4-5 grains of oat culture inoculum in contact with the roots, covering it with soil and making the soil firm. In later trials infected pieces of quince twigs were put singly along the root about two to three inches away from main stem and covered with soil. The potted plants were kept in the greenhouse and deciduous plants were taken out for short periods for chilling purposes during winter. Boxes were situated in the open and subject to all climatic variations. Artificial fertilizer was occasionally added when plants showed signs of hunger.

The following tables (II-IV) give details of the species, isolate used, maximum and minimum period after which the plants were killed. It will be seen that with the same variety and the same isolate there is considerable variation in the period after which plants were killed. Under more favourable conditions in greenhouse the total number of plants killed was, in general, more than in the box tests. Minimum period required for killing was also less under greenhouse conditions than the boxes.

Table II

Showing susceptibility of species to various isolates and the period after which the plants were killed.

Name of plant.	Isolate used.	No. of plants used.	No. of plants killed.	Period after which dead, in months	
				Minimum	Maximum
Almond	1	2	2	$2\frac{3}{4}$	
	5	2	1	$6\frac{1}{2}$	
	1	1	1	$4\frac{1}{4}$	
	4	1	1	3	
Apple	1	2	2	$2\frac{3}{4}$	$5\frac{3}{4}$
	5	2	-		
Camelia	4	1	1	9	
	1	1	-		
Citrus : Rehoba Palestine sour	1	12	4	1	$2\frac{3}{4}$
	2	12	3	$1\frac{1}{4}$	$2\frac{3}{4}$
	3	12	7	$1\frac{1}{4}$	$4\frac{3}{4}$
	4	12	10	$\frac{1}{2}$	$4\frac{3}{4}$
	5	12	3	$\frac{1}{2}$	$7\frac{3}{4}$
	7	12	9	$1\frac{1}{4}$	$3\frac{1}{2}$
	8	12	6	2	$3\frac{1}{2}$
Rough lemon	1	6	3	2	$4\frac{1}{2}$
	2	6	4	$\frac{1}{4}$	$3\frac{1}{2}$
	3	6	6	$1\frac{1}{2}$	$4\frac{1}{2}$
	4	6	5	$\frac{1}{2}$	$7\frac{1}{2}$
	5	5	3	$\frac{1}{2}$	$7\frac{1}{2}$
	7	5	4	$\frac{1}{2}$	$4\frac{1}{2}$
Cusri Sour orange	1	6	2	$1\frac{1}{4}$	2
	2	6	3	$\frac{3}{4}$	$3\frac{1}{4}$
	3	6	4	$1\frac{1}{4}$	$7\frac{3}{4}$
	4	6	6	$\frac{1}{2}$	$8\frac{3}{4}$
	5	6	4	$\frac{1}{2}$	$4\frac{1}{4}$
	7	6	4	$\frac{1}{2}$	$2\frac{1}{4}$
	8	5	3	2	$7\frac{1}{2}$

Name of Plant	Isolate used	No. of plants used	No. of plants killed.	Period after which dead, in months	
				Minimum	Maximum
Sweet orange large plants from Riverside	1	2	—		
	5	3	—		
	4	1	—		
	7	6	—		
Sweet orange large plants	1	7	—		
	2	6	—		
	3	7	—	$2\frac{3}{4}$	
	1	7	—		
	5	7	—		
Citrus trifoliata	1	7	—		
	2	7	—		
	3	7	3	2	4
	4	7	2	$\frac{3}{4}$	3
	7	7	3	2	
Valencia orange large plants	1	2	—		
Cotoneaster francheti	4	1	1	3	
Canosa	4	5	4	$1\frac{1}{4}$	$1\frac{3}{4}$
	1	5	5	$\frac{3}{4}$	$4\frac{1}{2}$
	5	2	2	2	3
Fig	4	2	2	$1\frac{1}{2}$	$2\frac{1}{2}$
	1	1	1	2	
	1	1	1	$6\frac{1}{4}$	
	5	1	1	$4\frac{1}{2}$	
Grape, Teleki 5A	4	3	—		
	1	2	—		
	7	3	—		
"93-5	4	2	1	$5\frac{1}{4}$	
"3309	2	2	2	4	$5\frac{1}{2}$
	4	2	1	$5\frac{1}{2}$	
	5	2	—		
	7	2	1	$5\frac{1}{2}$	
	8	2	1	9	

Name of plant	Isolate used	No. of plant used	No. of plants killed	Period after which dead in month	
				Minimum	Maximum
"Unknown pedigree	1	2	1	7½	
	4	2	—		
	7	2	—		
Holodiscus discolor	1	1	1	8½	
Jeffrey pine	1	2	2	2¾	3¾
ontbretia	4	1	1	3½	
S. W. Massina cherry on Mahaleb	5	2	2	3½	6½
Napolean cherry on Mahaleb.	1	2	2	6	12½
	1	1	1	2	
	3	2	2	3	3½
	4	1	1	2¼	
Napolean on Mazzard	1	1	1	6	
	5	1	1	5¾	
Napon on Mazzard	5	1	1	3¼	
Olive	1	2	1	8¼	
	5	2	1	3½	
Peoony	1	1	I	1¼	
	1	1	1	¾	
	5	1	1	2¼	
Peach, 3-4yr. old	1	2	—		
	5	2	—		
Lovell 1 yr.	1	7	-		
	2	7	—		
	3	7	—		
	4	7	2	7	8
	5	7	1	6½	
	7	7	1	5	
	8	6	2	3	7

Name of plant	Isolate used	No. of plants used	No. of plants killed	Period after which dead in month	
				Minimum	Maximum
Willow	1	1	—		
Pear	1	3	2	6¼	11
	4	4	2	6	13
	5	3	1	7	
Pittosporum tobira	4	2	—		
Plum C-71	1	1	1	1¼	
	2	3	1	3½	
	5	4	2	3½	
Marianna 2624	1	1	1	2¾	
"Myrobalan	1	3	2	2¾	5½
	1	4	—		
	4	3	1	4¼	
	4	2	—		
	5	4	2	3½	9
"St. Julian	1	2	—		
	1	3	3	3½	5½
	4	1	1	5½	
Prunus ilicifolia	1	2	1	13½	
Quince	1	2	2	1¼	3
	4	2	2	2¼	
Rubus					
Raspberry	1	1	plants	bushy, no vigorous shoots	
,, 302	5	2	plants	stunted	
,, Cuthbert	1	4	,,	,,	
	4	4	,,	,,	
	5	4	,,	,,	
	8	2	,,	,,	
R. ursinus	1	5	Plants	stunted	
	4	4	,,	,,	
	5	1	1	2	
Strawberry	1	3	Parent runners	plants killed, new established	
	4	3	3	¾	
	5	3	3	2	
	8	3	3	2	
Soap bark (Quillaja saponaria)	1	2	—		
	4	1	—		
Sugar pine	1	2	2	11½	14
Walnut : Black	1	1	1	2¾	
"Persian	5	1	1	2¾	

Table III.

Showing results of inoculations on plants grown in large soil boxes put in the open. Box Test I.

Name of the plant	Isolate used	No. of plants used	No. of plants killed	Period after which dead in month.	
				Minimum	Maximum
BOX TEST I					
Almond	1	5	2	4½	
Apple	1	4	4	3¼	4½
Citrus:					
C .trifoliata	1	4	2	3¼	4¼
Madam vinus sweet	1	4	3	4¼	7¼
Palestine sour	1	4	4	3½	10½
Rough lemon	1	4	3	4	14¼
Sour orange	1	4	2	3½	
Sweet orange	1	4	3	3½	7¼
Windsor grape fruit	1	4	2	4	5
Strawberry	1	3	2	8½	
Walnut	1	3	2	4¼	6¾
BOX TEST II					
Citrus:					
C. trifoliata	1	14	—		
Citrus sp	1	4	2	2	3
Rehoba palestine sour	1	7	4	2¾	6
Grape: 39-5	1	4	—		
57-R	1	3	1	5½	
99-R	1	5	2	6½	8½
110-R	1	5	2	3¼	
420-A	1	2	—		
O-1202	1	4	—		
1616	1	1			
3309	1	6	—		
Plum XX	1	4	—		
"Mariana 2623	1	3	—		
"Myrobalan	1	4	—		
Rosa multiflora	1	4	—		
Miscellaneous :					
Grass, Oxalis sp., Polygonum sp.	were seen to be killed.				

There appears to be greater mortality of citrus species in Box Test I as compared to Box Test 2. This shows that young plants are more susceptible at transplanting than after establishment in soil. The results for other kinds of plants are not comparable.

(*d*) RESISTANCE OF SPECIES. The number of some species used in the greenhouse experiments was not large, so that results which indicate resistance cannot be regarded as absolute. Indication of resistance in the present trials can, however, form a basis for further work of sifting and selection. No case of great resistance has been found in fruit plants in these experiments. *Pittosporum tobira*, *Quillaja saponaria* and willow survived, although *Salix* sp. has been recorded in literature to be attacked by *R. necatrix*.

Large plants of sweet orange were not affected by isolate Nos. 1, 2, 4, 5, and 7. However, Isolate No. 3, killed two large plants. Valencia was inoculated with isolate No. 1 but no plant was killed. Three to four year old plants were not killed even after two years of exposure to isolates 1 to 5. Among young citrus root stocks tried *Citrus trifoliata* seems to resist the attack better than others although it is not immune. All *C. trifoliata* plants after one week of inoculation shed their leaves as if all were going to die but later on they gradually recovered and formed new leaves.

Myrobalan C-1 was susceptible to isolates 1 and 2. This experiment needs repetition. Myrobalan and Mariana have shown fair resistance to disease in box tests.

(*e*) OTHER SUSCEPTIBILITY TRIALS WITH CITRUS ROOT STOCKS. Three-to-four-months old seedlings of Rough lemon, Sour Orange, Rehoba Palestine sour and *Citrus trifoliata* were potted and left for a month to become established. Plants were then inoculated with isolates number 1, 2, 3, 4, 5, 7 and 8. Number of plants used in each case and those killed are given in table IV.

Table IV.

Showing the number of Citrus plants killed within eight months of inoculation.

(Denominator is the total number of plants inoculated).

Species used.	Isolates tried						
	1-cherry	2-cherry	3-peony	4-peony	5-walnut	7-pear	8-apple
Rough lemon	3/6	4/6	6/6	5/6	3/5	4/5	—
Sour orange	2/6	3/6	4/6	6/6	4/6	4/6	2/5
Rehoba Palestine sour	4/12	3/12	7/12	10/12	3/12	9/12	6/12
Citrus trifoliata	0/7	0/7	3/7	2/7	—	3/7	

Tabulated results show that *Citrus trifoliata* is least susceptible while rough lemon showed a high death rate with isolate Nos. 1, 2, 3 and 7, but Sour orange showed highest kill with No. 4. Although percentage of death varies with the isolate, it is apparent that Rehoba Plestine sour falls next to *Citrus trifoliata* in the scale of lower percentage of death of plants.

Isolates 3 and 4 from Paeony were more virulent on citrus species tried than others. Next in order of pathogenicity was No. 7 from pear while 1, 2, and 8 were least pathogenic.

(*f*) TIME REQUIRED TO KILL THE PLANTS. The period elapsing before plants are killed is very variable. Findings of various workers are given in table V.

Table V.

Showing the time required to kill the plants.

Species	Time required to kill	Remarks
Grapevines (25 yrs. old)	14-18 months.	Millardet (1879)
Bean (young plants)	most easily killed.	Hartig (1880, 1883, 1894)
potatoes	Never germinate	Hartig (1880, 1883, 1894)
Vines	15-18 months	Viala (1891)
Coniferous deciduous trees (3-4 yrs. old)	1-2 months	Viala (1891)
Young plants	6 months	Under warm conditions
Larger plants	2-3 yrs sometimes	
	5-6 years.	,,
Fruit trees	2-3 years	,,
Grape vines	3 years.	Blunno (1911)

Greenhouse experiments conducted by the writer show that the time varied from a few weeks to many months. Data are given in tables (II, III.) Under field conditions pear replants may linger on for a number of years declining in health before they die or they may die during the year of planting. The period, is clearly dependent on the climate, soil moisture, age and the species. The younger the plant or shorter the stature and root system, the more easily and earlier it is killed.

(*g*) MODE AND RATE OF SPREAD OF THE DISEASE. Hartig (1880, 1883, 1894) observed that the disease spreads over an area of 0.1 hectare (0.25 acres) of vines within a year. Millardet (1879) also reported of slow death.

Wight (1889) states that sometimes a tree here and there dies, sometimes a whole row and very often acres are swept away. According to Viala (1891 *R. necatrix* root rot is slow but progressive. It is rapid if planting is close and one is compelled to abandon the cultivation of vines or fruit trees for a number of years.

The disease in California has increased since earlier reports. A few trees here and there are left over in a patch otherwise cleared by the disease (Fig. 17). On the whole rate of disease is more rapid than that of oak root fungus. In one orchard more than five acres of the orchard was destroyed.

Infection occurs through the openings or cracks resulting from emergence of lateral roots. If the mycelium finds a wound it penetrates easily. The conidia according to Viala are a source of dissemination of the fungus by air but it is very doubtful if conidia germinate.

The fungus, in the opinion of writer, requires warm and humid conditions in order to attack healthy plants. It penetrates the root bark either directly or at first grows on the surface and then penetrates it. Wounds, dead portions of the roots, lenticels, cracks and root emergence fissures are common courts of infection. In one of the orchards in which the fungus was present, portions of roots injured by cultivator were cultured and gave positive results, although the tree was apparently healthy.

The disease is initiated by subterranean mycelium in moist surroundings when the fungus spreads through the soil and makes contact with healthy roots. Mycelium grows in soil in the form of rich abundant strands or as a cottony white mass from the root of diseased plant.

It is now known that ascospores germinate after a long time and gerimnability is low. They either escape after the disintegeration or breaking up of perithecium or ooze out in a mucilaginous mass from the ostiole; so the spread is not through wind but by mechanical contacts with objects and transported either by insects, animals or other moving objects. The dispersal by rain is more likely. However taking into consideration the rarity of perithecia and oozing out of spores in mucilage, ascospores cannot be said to play a significant role in the spread of this fungus and a source of inoculum.

The predominant source of inoculum is mycelium in various forms. Sclerotia overwinter and mycelial strands serve to spread the

fungus. This may infect vine cuttings buried in the contaminated soil and be carried on these, to places where they are planted. Use of infected nursery stock has probably introduced the fungus in many cases.

Root contacts are a very important source of infection of healthy plants. The pattern of disease definitely indicates this fact as it usually spreads in ever increasing area from one or a few foci.

If the soil contains abundant humus and wood, these may serve as food bases and spread of infection to a distance, as has been pointed out previously. Similarly infested soil sticking to any mobile object may act as a source of inoculum.

The method of transfer of inoculum on agricultural tools is very significant, as is evident from the pattern of disease which generally is not a continuous area but a few apparently healthy trees are found here and there.

The fungus is also able to spread through manuring with leaves, dry branches and cleanings of forest or with superficial earth of the same forest where the disease exists.

The disease in California is found both in irrigated and non-irrigated orchards and the mapped orchards do show a clear correlation between the spread of disease and direction of water. The water as an agency for the transport of infested wood is probably very important.

(*h*) CONDITIONS FAVOURING THE SPREAD OF DISEASE: *Rosellinia* species spread in plantations under two extreme conditions. The first category of environment inctude high rainfall, high temperatures and abundant debris or leaf mould in and on the soil. The second set of conditions is seen in localities where the rainfall is not heavy, and temperatures are comparatively cooler as in many temperate regions. The spread under such conditions is slow and mainly through root contacts, old dead roots and stumps acting as food substrates, Garrett (1944), Gadd (1928), Fawcett (1936) and Nowell (1915, 1916a, 1916b, 1916c, 1916d, 1919, 1920, 1923).

An increase in root rot due to plant residues or organic matter in the soil can occur through : (i) direct stimulation of growth activity of the parasite, (ii) changes in microbial balance in the rhizosphere, (iii) depletion or unavailability of soil nutrients during microbial decomposition of added residues, and lastly (iv) the direct toxic action of these residues

or their decomposition products (Cochran 1948). First hypothesis seems to be most plausible reason so far as this diseases is concerned. Other hypotheses, however, need further testing.

Some workers have suspected that root injury under very wet and water-logged conditions was favourable to attack of *R. necatrix*.

(i) *Soil and water in relation to disease.* Hartig (1880, 1883, 1894) observed that drier upper part of the subterranean stock remained free of fungus. Moist, rich and strongly fertilized soil was very favourable to the development of fungus. The disease exists more often in clayey or marly soils with impermeable subsoil (Viala 1891). Littoral sand of the mediterranean belt was free of attack by *R. necatrix*. The disease has been reported on compact and rather dry limy-clay soil rich in siliceous earth. (Millardet 1879). Wight (1889) never found the disease in clay or other damp soils but always soils overlying a porous subsoil or which may be well drained and never occurs with great severity (Scribner 1890).

Starnes (1895) indicated that the disease is less prevalent in red clay sections than in areas less well drained. Pierce (1892) also mentioned that *Dematophora* develops more readily in more compact soils. Soils of a sandy nature being less infested.

Wetness of soil, in the opinion of Ferraris (1909) is the prime cause which favours development and spread of disease. In very loose sandy or dry soil, *Rosellinia* root rot is never manifest but is very frequent in compact impermeable wet soil. The disease developed very frequently where vines or other plants grow on sites recently deforested. The fungus grows saprophytically in rich soil and causes quick infection.

From the foregoing account it appears that the fungus can exist in a wide variety of soils from clay, calcareous, granitic to sandy soils. In California the disease occurs on Watsonville light loam, clay loam, sandy clay, sandy loam and silt loam. It is not restricted to moist valleys or low lying lands but occurs in comparatively drier places too. The disease occurs both in irrigated and non-irrigated orchards.

(ii) *Temperature relations of the disease.* The influence of temperature on the development of root rot is secondary to that of moisture; the progress is most rapid between 70° and 80°F (21° C to 26.6°C), Rivera (1946) found that infection of very young layer roots of vine

varieties occurrrd 24 hours after inoculation at 25 C, in humid conditions and plants were killed in 6-7 days. At 8° C, it took 8 days to reach the same degree of infection as reached at 25 C within 24 hours. Exposure to a temperature of 43° C for 6 hours in wet conditions was sufficient to kill the mycelium of *R. necatrix* when growing on dead materials. On living susceptible plants 10 hours at 42° C, 7 hours at 45° C were necessary to kill this mycelium.

Experiments conducted by the writer show that the fungus requires high temperatures for its spread and the progress is more rapid in summer after irrigation than at other times. Laboratory tests indicate that the fungus is very active over a wide range of temperatures i. e. 19-28° C with maximum growth at 22° C. Minimum lethal temperature for the fungus was 34° C. Because heat penetration in soil is generally very slow, fungus survives at lower depths in summer around finer roots until conditions of moisture and temperature are suitable for its spread to a distance near the surface. In winter it survives as sclerotial masses and crusts as well as inside wood buried under soil. In spring and towards fall, the temperatures are conducive to its growth provided proper moisture conditions extst.

5 CONTROL

On account of long period over which this disease has been known, every pathologist who had to deal with this insidious fungus, has attempted to control it by eradication, prophylaxis or soil treatment. The control of this fungus is rather difficult because of its resistance to drought, tolerance of soil acidity over a wide range, wide host range, deep penetration into the soil, and resistance to various common fungicides.

Various control measures have been suggested by different workers which may be summarised below :—

1. Isolation trenches, 100 cms wide and 60-80 cms deep have been recommended. The trench, as a matter of fact, should be deeper at least up to five feet if not more, so that all laterally spreading roots may be prevented from growing through and later serving as medium for the spread of fungus. Trenches must be kept clean of leaves and debris, otherwise the very purpose of isolation will be defeated.

2. Trenching with application of lime, iron sulphate, arsenic oxide, and products of coal tar distillation have been suggested as barriers but is not a practial proposition, because roots coming in contact with

poisonous barriers such as white arsenic, would absorb enough arsenic to injure the plants. Other chemicals used by various workers are not lasting enough to be effective against this fungus because barriers must stay in the soil for many years to be feasible. In one instance of *A. mellea* attack, a galvanized iron sheet was buried deep around the affected area but such a treatment is too expensive to be practicable on a large scale. Moreover, unless it is a continuous one there will be ample chances of the fungus escaping from crevices of overlapping sheets of iron.

3. Removal of diseased plants and burning diseased material in pits from where it is dug out, has its good points but this alone is not sufficient. Digging should be done with care not letting any infected material, wood chips or soil to go out of the affected area. Repeated inspection and eradication of diseased stock over a period of years is essential.

4. Drainage of the soil where soil is too wet is advisable.

5. Fallowing and repeated cultivation (Nattrass 1927, Moore 1939 and Pierce 1892) have been advocated on the presumption that fungus dies in drier conditions. This is partly true because vegetative mycelium in soil may be killed but the mycelial strands situated deep down and in pieces of wood can still survive for a long time. Real purpose of fallowing is to starve the fungus and to accomplish this the soil must be kept free from debris, wood chips and other plant material.

6. Surgical treatment of diseased plants has been suggested by some workers. After removal of diseased roots, lime-sulphur, Bordeaux mixture, and copper sulphate solution have been used as root washes. But this treatment has very little value as a practical means of control because not all the affected roots can be found and there are chances for the fungus to start its activity from undetected foci.

7. Breeding for resistance has been almost entirely neglected.

8. Soil treatment by steam sterilization may be practicable under greenhouse conditions but in orchards it is not practicable because fungus may penetrate as deep as 90 inches or more.

9. Soil treatment with chemicals. Treatment of soil with lime has been suggested by Suba Rao (1941), Nowell (1915, 1916a, 1916b, 1916c, 1916d, 1919, 1920, 1923), Voglino (1924), and Fawcett (1936). They based their recommendations for liming of soil on account of cheapness and easy availability of lime but how far it is effective, no concrete data are available.

Hartig (1880, 1883, 1894) did not favour the use of chemicals but various soil treatments with sulphur, gypsum, iron sulphate, potassium salts, phosphates have been advocated by other workers. Iron sulphate will make the soil more acid and if it is already on acid or neutral side, the effect may be adverse. These salts, except sulphur, are not effective fungicides although they may correct deficiency symptoms. The use of copper as a soil dressing (50 gms, per plant) was injurious and lower doses (1% solution of copper sulphate) were found better by Mercuir

(1928) but how far such a treatment will be lasting is again a question. Mercuri also claimed calcium cyanamide, (15-30 gms per plant) to be beneficial in the control of disease in artichokes but nothing is known about its effectiveness in case of woody perenials. There is, therefore no effective fungicide which is fairly cheap and easily available at this stage.

As a last resort plant pathologists have tried sterilization of soil with chemicals such as carbon disulphide. Although some claimed it to be effective in the presence of living plants in field yet as far as the experience of the writer and other later workers goes, carbon disulphide is poisonous to plants and kills the roots. Carbon disulphide as a soil treatment after removal of roots is an established practice against *A. mellea* and has been claimed by Frank (1880), Delacroix (1902), Patouillard (1910) to be effective against *R. necatrix* but Prilleaux (1881) found it of little use.

Harold E. Thomas and other (unpublished data) carried out tests with carbon disulphide in 1938. Two diseased trees were treated with two brands of carbon disulphide at double the dose for *A. mellea* but the treatment was not effective. In a second test in 1940 with double dose plus depth treatment, the fungus was killed down to 40 inches.

Tests were carried out in Berkeley (California) in one quart jars with different chemicals by filling the jars with soil, inoculating infected pieces of roots in these vertically and then leaving them for five days before the chemicals listed in the table below were used in 1cc, 0.5 cc and 0.1cc quantities and 0.5cc, 1cc and 2cc. Cultures were taken after two weeks. The results are given in the table IV. Methyl bromide gas was at 300cc, 600cc, 1200cc and 2400cc per jar. The result are shown in table (VII).

Table VI.

Quart jar tests with chemicals against Rosellinia Cultures on twigs.

(Numbers indicate the cultures of Dematophora obtained. Denominator shows the total number of cultures tried).

Chemical tried	1938				1939	
	1.0cc	0.5cc	0.1cc	2.0cc	1.0cc	0.5cc
Ammonium hydrosulphide	0/16	7/16	0/16	4/15	0/15	2/15
Bromopicrin	0	5	10	0	0	0
Chloropicrin	0	0	6	0	0	0
Chlorobenzene	0/16	1/56	7/16	0/15	0/15	0/15
Carbon disulphide	0	0	0	0	0	0
Octyl alcohol	0	5	1	not used		
Penta chlorethane	0	0	2	0	0	0
Propylene oxide	1	0	4	0	0	0
Ethylene dichloride	0	0	8	0	0	0
Tetra chlorethane	0	0	2	0	0	0
Trichlor ethylene	0	0	0	0	0	0

Table VII.

Cultures obtained after Methyl bromide treatment.

Period after Treatment.	Volume of gas used.				
	2400cc	1200cc	600cc	300cc	check
30 days	0	59	71	74	71
60 "	0	57	72	70	72
90 "	2	74	71	69	67

From the above tables one can see that ammonium hydrosulphide, bromopicrin, octyl/alcohol, trichlor-ethylene, did not give a complete kill. All others proved to be toxic at 0.5 cc per jar. Methyl bromide 2400 cc (gas) was effective in killilg the fungus but 1200 cc was not.

10. The effect of different chemicals on the fungus in soil.—A number of chemicals which are listed below were tried using different dosages and allowing the soil with inoculum to remain undisturbed after the treatment for difierent periods of time i. e. dosage and period after treatment were varied. Different isolates of fungus were used in this series of experiments.

Inoculum was prepared by growing the fungus on small bits of twigs of quince or pear. These bits of twigs were tied in pairs and

labelled. Four such labelled pairs were deposited at different levels of the soil in cans. The total capacity of each can was 30 gallons. The arrangement of inoculum at each level is shown below :

a
d
b c

Usually in preliminary trials two levels of soil depth were selected viz. 12 and 24 inches. In more detailed experiments the inoculum was placed at 1, 6, 12, 18, and 24 inches. The required quantity of volatile chemicals was poured in one inch diameter hole made in the centre of packed soil. Generally the chemical was applied at twelve inch levels and in some cases at 6 and 18 inch levels. Chemicals were poured through a glass tube, and the tube allowed to drain off for a while before removing. After this, the hole was filled with soil and packed tightly. Soil surface was sprinkled with water and covered with wet burlap bag which in turn was covered with a loose metal lid. The cans were emptied after definite periods, usually four days; or 8, 12 or 24 days and the soil sifted through a screen to recover the inoculum. Inoculum bits were washed in a strong current of water to get rid of soil and placed on a moist sterile paper pad in petri dishes. Observations were recorded after eight days and twice later in a period of two weeks. The quantity of chemical used, post-treatment period, soil moisture, soil and air temperature were recorded and tabulated. N.G. The following chemicals were tried :

Allyl acetate, allyl alcohol, allyl bromide, allyl chloride, allyl formate, ammonium hydrosulphide, bromopicrin, carbon disulphide, carbon tetrachloride, chloroform, chloropicrin, chloropicrin plus ethylene dibromide (Dowfume 10), dithane, ethylene dibromide (Dowfume 10), formaldehyde, isocaproic acid, methylal, nitroethane, nitromethane, penta chlorethane, propylene bromide, tetra chlorethylene and tetra chlorethane.

Results: Two dosages of 10 and 20 cc of allyl acetate were tested and inoculum at the point of application of chemical was only killed. Allyl formate and allyl chloride had the same effect.

With allyl alcohol no difference was observed between two dosages, viz 10 and 20 cc, and there was slightly better kill with it than with allyl acetate.

Allyl bromide was used in seven tests at dosages of 5 and 10 ccs. Five ccs of this were as effective as 20 cc of chloropicrin or 50 cc of (10%) ethylene dibromide (Dowfume 10). The chemical was effective down to 18-20 inches with the dosages tried.

Two dosages of ammonium hydrosulphide, 5 and 10 cc had no effect on the fungus taken out after four days post-treatment period. At 20 cc dosage the fungus inoculum immediately in contact with the chemical at 12″ level was killed.

Bromopicrin was used at 5 and 10 cc dosages at 12″. This proved to be inferior to chloropicrin and was ineffective against the fungus.

Seven tests were conducted with carbon disulphide using 10,20 and 30 cc of the chemical at different depths. Ten and twenty cc dosages with four days post-treatment period were ineffective except for central inoculum at 12″. Two tests with 30 cc at 12″ with 14 days as post-treatment period gave inconsistent results showing some kill at 12″ and 24″. Thirty ccs applied at 6″ showed even poorer results as compared to 12″ applications. The results so far have not been encouraging as regards efficacy of carbon disulphide against the fungus under conditions of this experiment.

With carbon tetrachloride two dosages of 10 cc and 20 cc applied and left for 4 days had no effect on the viability of fungus except on inoculum at 12″ level which was killed.

Chloroform had no effect on fungus at any level except one centrally located inoculum receiving the material in greatest concentration.

Chloropicrin was used in seven tests, at 5, 10 and 20 cc dosages at 12″ and 20 cc at 6″. Post-treatment periods of 2,4 and 6 days were tested. Chloropicrin at 5 and 10 cc doses was potent enough to kill all pieces of inoculum at the level of application but penetration to more than six inches up and down was not enough to kill the fungus. Twenty cc was much more effective and penetrated 12″ deeper from the point of application and killed inoculum at 24″ but not at 1″ level. Comparing the results of twenty cc applications at 12″ and 6″ it is clear that lethal effect tapers off towards either extremity because when the dose (20 cc) was applied at 6″ the inoculum at 1″ was killed but the deepest at 24″ was not affected and reverse was the case with 12″ application. It can safely be assumed therefore, that the gas diffused ineffective concentrations against this fungus down to 18″ only.

In one experiment 5 cc of chloropicrin plus 10 cc of ethylene dibromide and in the second 2.5 cc of chloropicrin plus 10 cc of ethylene dibromide were used. These mixtures had no significant synergistic effect and only inoculum at the level of application of chemical was killed. Effect was the same as 5 cc of chloropicrin alone. The effect of 2.5 cc of chloropicrin plus ethylene dibromide was the same as indicated above. Ethylene dibromide alone at 10 cc dosage had the same effect as 5 cc chloropicrin. Mixtures had no build-up effect.

Ten and 20 cc of dithane used at 12″ did not have any effect on the fungus.

Ten per cent solution of ethylene dibromide in an organic solvent put on market by Dow Chemical Co. as 'Dowfume 10' was used in these experiments. 10 cc alone in one test had as good an effect as chloropicrin in an equivalent quantity Twenty cc dose of ethylene dibromide (10%) gave poor results. This cast doubt on the efficacy of this chemical at lower doses. Therefore, 50 cc dose was tried and results were inconsistent perhaps due to low temperatures prevailing during the test period. In the second test with 50 cc, a 50% kill at 1% level and complete killing at 12″ and 24″ were obtained. These results compare favourably with those obtained with 20 cc dose of chloropicrin.

Formalin used in 10 and 20 cc quantities for 4-days period has no lethal effect on the fungus. Isocaproic acid was used in 10 cc dose, except 12″ level central inoculum, none was killed. Dosages of 10 and 20 cc of methylal had no effect on the fungus. Nitroethane and nitromethane were used in 10 and 20 cc doses at 12″ and only the central inoculum at 12″ depth was killed.

Pentachlorethane used at 10,20,30 cc doses at 12″ had no effect on the fungus except that it killed the central inoculum at 30 cc dosage at 12″ level. Ten cc dose of propylene bromide had the same effect as nitromethane but at 20 cc dosage the lethal effect was slightly more, yet not great. Tetrachlorethylene was tried in three dosage levels namely 10, 20 and 30 cc at 12″. With the exception of central inoculum at 12″ no kill was obtained. Ten cc of tetrochlorethane used at 12″ level did not kill the fungus although it was effective against *Phymatotrichum* (Ezkiel & Taubenhaus 1934).

Thus from the lot of chemicals tried only allyl bromide has shown promise at low doses. Ethylene dibromide (10%) 50 cc had the same effect as 5 and 10 cc of ally bromide or 20 cc of chloropicrin. Carbon

disulphide is apparently ineffective against this fungus under conditions of experiment. Higher temperature may have different effect. Further experiments are needed in this respect.

ACKNOWLEDGEMENT

The work on the investigation reported above was done under the guidance of Dr. H. E. Thomas, Dr. M. W. Gardner and Dr. L. Bonar. The author is very grateful to them for their constant help, encouragement and guidance.

SUMMARY

Biology and pathology of 12 species has been discussed.

Rosellinia necatrix is world wide in distribution in temperate climates. It affects 170 species 63 genera and thirty families of higher plants and three algae.

General symptoms of disease are gradual decline, defoliation, wilting and stunting. The tree in the beginning of attack produces ana bundant crop which may or may not reach maturity. New shoots or suckers are produced in an attempt to survive but these in turn are killed. There is a general reduction in size, change in shape and density of color of leaves In advanced stages of attack stagheadedness and die-back are common symptoms. The fungus may be found on roots, in the soil or on its surface, depending on moisture and temperature conditions. It sometimes girdles the base of stem at the root crown. In some bush fruits new canes continue to appear after infection and the fungus insidiously continues to kill them. Ultimately the plant becomes so weak that no vigorous canes are produced, it assumes a stunted bushy appearence and eventually dies.

The fungus spreads through bark into wood. Main path in wood is through medullary rays. It forms discontinuous ribbons of mycelium underneath bark and on the surface of wood. Mycelial strands or ribbons emerge bursting through the bark and forming white swellings or nodules which later become a black crust upon which coremia arise under moist and warm conditions. Mycelium also spreads in soil, debris, leaf mould and wood chips as white flocculent lax mycelial multicostate fans.

Coremia arise in groups of 3-12, conidia seldom germinate, if ever. Perithecia are dark brownish grey, globular depressed a little at the apex with a black projecting papilla with pore ; intermixed with coremia. Asci

8-spored, filiform, with a thick plug at the tip, coloured blue with iodine; spores black, spindle shaped, asymmetrical somewhat flat on one side Five percent lactic treatment is sufficient to cause 3% of the spores to germinate.

The period during which plants are killed is very variable even for the same species and same isolate or strain of the fungus. Young plants may be killed in three weeks to several months. An older plant may take some years before it actually dies. The killing period is dependent on moisture, temperature and variety of plant.

In susceptibility trials with citrus seedlings, *Citrus trifoliata* was found to be least affected whereas rough lemon was most susceptible. The fungus isolate from paeonies was most virulent and one from pear was next in order, in their effect on 6 month old citrus seedlings. Older sweet orange plants showed very low rate of death after 19 months.

The factors conducive to spread of disease are soil moisture and temperature. As moisture decreases, the fungus goes deeper following the roots and may sometimes be found 9ft. below the surface. The fungus occurs both in irrigated and non-irrigated orchards.

Infected plant parts may be dragged along by cultivator tools and thus disseminate the disease. The injuries caused on the roots by the agricultural implements also offer foci for easy entrance of the fungus.

Control of the fungus is rather difficult because of its resistance to drought, soil acidity over wide range, large number of hosts, deep penetration into the soil and resistance to various common fungicides.

Eradication and prophylactic methods have been discussed in the text. Sterilization of the soil by chemicals was also attempted.

One of the earliest attempts to sterilize the soil was with carbon disulphide. The fungus was killed with double the dose for *A. mellea* plus the depth treatment; upto 40 inches, yet the success is not unqualified. In the trials reported here covered garbage cans of 30 gallon capacity filled with soil were used. 30 cc of carbon disulphide for two weeks had no effect on the fungus.

Twenty three othér chemicals listed in the text were used in fungicide trials. Ethylene dibromide 50 cc (10% solution = Dowfune 10) or 5 cc (10% solution in organic solvent = Dowfune 10) or 5 cc allyl bromide have killed the fungus down to 18-20 inches but some of it near

the surface escaped. These two chemicals show promise of being effective against this fungus in the soil. Chloropicrin, 20 cc at 6'' killed the fungus at 18'', not 24 inches. When applied at 12'', it killed the fungus at 24'' but not at 1''.

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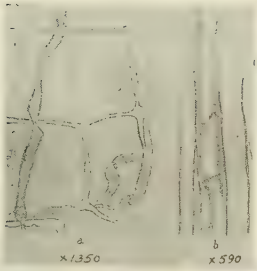
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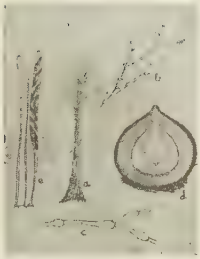

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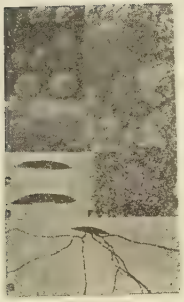

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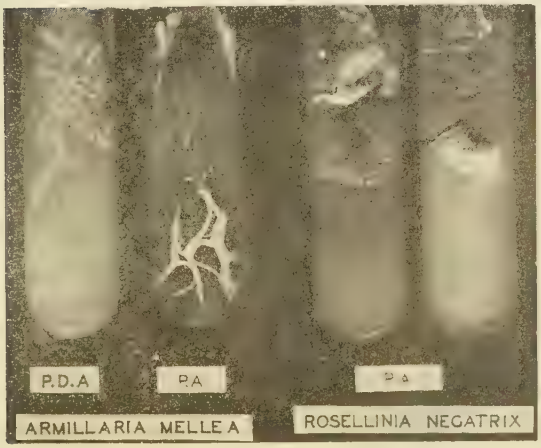
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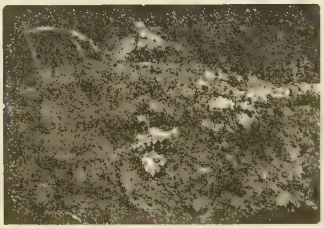

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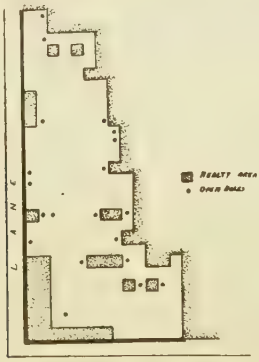

PATTERN OF DISEASE IN A PEAR ORCHARD

17

EXPLANATION OF FIGURES

Fig. 1. Hyphae of *Rosellinia necatrix* in wood.

Fig. 2. Morphological characters of *R. necatrix*.

(a) Coremium; *(b)* geniculate conidiophore; (*c*) swollen hyphae; *(d)* perithecia.

Fig. 3. Morphological characters of *R. necatrix*.
(*a* & *b*) Perithecia showing exuded mass; *(c)* spore showing distended epispore: *(d)* spore showing ventral slit partly broken; *(e)* perithecia on apple root; *(f)* coremial stage on apple root ; *(g)* germination of an ascospore.

Fig. 4 Mycelial fans and strands.

Fig 5. Rhizomorphic structures of *A. mellea* and *R. necatrix*.

Fig 6. Pear, diseased and healthy.

Fig. 7. Dead apple plants with mycelium in the soil.

Fig 8 Olive, diseased and healthy.

Fig. 9. Quince mycelium spreading along the roots.

Fig. 10. Plum, diseased and healthy.

Fig. 11. Quince, diseased and healthy.

Fig 12 Paeony, diseased and healthy.

Fig. 13. Walnut, diseased and healthy.

FiS. 14. Killed Citrus seedling with mycelium in the soil.

Fig. 15. Raspberry, diseased and healthy.

Fig. 16. Young apple tree root : mycelium spreading in the soil.

Fig 17. Pattern of disease in the pear orchard.

INDEX

New genera and species have been indicated in hold type.

Ahmad, S.,
see Mueller, E. & Ahmad, S.
Arslan, M., 74
Ascomycetes of Pakistan, 1
Buckleyurinae, 30
Buckleyuris, 31
Carrot
Cercospora carotae, on, 46
Cercospora carotae;, 46
Chrysanthemum leaves
Septoria chrysanthemella on, 47
Coccostroma capparidis, 15
Cochliobolus sporoboli, 8
Didymosphaeria
culmicola, 1
spinosa, 3
Drosicha stebbingi
Muscular system of, 96
Earias insulana
Rogas testaceus in, 86
Ephestia sericarium
Rogas testaceus in, 91
Flora of Karachi
Further contribution towards, 36
Funambulus pennanti
Vaginal smears of, 74
Gossypium Bakeri
Position of, 41
Haque, K. A.
see Latif et al.
Holwaya salicis, 9
Islam, A. S. & Imam, M. M., 41
Jafri, S. M. H., 36
Khan A. A.
see Latif, A. & Khan, A. A.
Khan, A. H., 199
Khan, I. U., 47
see also Nawaz, M. & Khan I.U.
Khan, M. R.
see Latif et al.
Khan, S. A., 45
Latif, A., Haque, K.A. & Khan, M. R., 143
Latif, A. & Khan, A. A., 96
Leveillula (Oidiopsis) taurica
New host of, 45
Mueller, E. & Ahmad, S., 1
Nasir, E., 63
Nawaz, M. & Khan, I. U., 46
Northern palm squirrel
Vaginal smears of, 74
Platyedra gossypiella
Rogas testaceus in, 87
Poecilocerus pictus
External anatomy of, 143
Reconstruction of genus *Trichuris*, 19
Rogas testaceus in 4 host species
Fate of, 84
Rosellinia necatrix
Biology and pathogenccity of, 199
Rudolphia, 29
Salamia, 31
Salt, G., 84
Sarwar, M. M., 19, 48
Septoria chrysanthemella, 47
Silene
apetala, 64
arenosa, 65

aucheriana, 65
citrina, 66
conoidea, 66
falconeriana, 66
griffithii, 66
inflata, 68
in W. Pakistan and N. W. Himalayas, 63
joerstadii, 68
kunawurensis, 68
moorcraftiana, 69
nana, 70
Revision of the genus, 63
tenuis, 70
tenuis var. *dasyphylla*, 70
Stilbocrea macrostoma, 12
Sylepta derogata
Rogas testaceus in, 88
Tichothecium pygmaeum, 6
Trematosphaeria verrucosa, 12
Trichurinae, 27
Trichuris
discolor, 50
ovis, 23
Reconstruction of the genus, 19
Some little known spp. of, 48
spiricollis, 48
Taxonomy and morphology of, 16
tenuis, 56
trichura, 23
unguiculatus, 53
vondwei, 58
Vaginal smears, 74

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BIOLOGICAL SOCIETY OF PAKISTAN

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